

COMETS AND THE SUN

NEW THEORIES REGARDING THEIR STRUCTURE

JOHN W. WEIR





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COMETS
AND THE SUN



ENLARGED COPY OF PHOTOGRAPH OF HALLEY'S COMET.

[Kindly contributed by the late A. S. Hough, Esq., F.R.S., F.R.A.S., Astronomer at the Cape.]

COMETS AND THE SUN

NEW THEORIES REGARDING THEIR STRUCTURE

BY

JOHN W. WEIR, M.D., F.R.C.S. ED.

The Sun is the noblest work of Almighty God
(*Schiaparelli*)

WITH ILLUSTRATIONS

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*TO THE
MEMORY OF MY FATHER*

FOREWORD

BY

SENATOR A. W. ROBERTS, D.Sc., F.R.A.S.

IT is with great pleasure that I seek to write an appreciation of this work — a labour of love — of my friend Dr. Weir.

To his inquiry on the constitution of comets Dr. Weir has brought unremitting labour, much reading and great ability. His own words will abundantly exemplify the new theory which he submits regarding the outer envelope of comets, and of their relation to the corona, and to other similar phenomena.

His criticisms of the various views which have been put forward by astronomers as explanatory both of direction and form of comets' tails ought to command attention, as they are expressed with grace and with judgment.

The theory which Dr. Weir suggests is that comets are contained in, or bounded by, an envelope. He brings to the support of his contention various descriptions, drawings and photographs of comets, in all of which there is clear evidence of a distinct division between the body of the comet and the surrounding space. The sides of the tails of the various comets delineated do not fade away indistinctly but are clearly defined by boundary lines.

Dr. Weir's explanation of the formation and even existence of this envelope will naturally rouse criticism on the part of both physicists and mathematicians. This is inevitable. But this much must be said in favour of the theory: that there is less to be said against it than against each of the many theories that have been urged in the past to explain the form, structure and direction of a comet's tail. Indeed most of these theories have been set aside as wholly inadequate to explain evident appearances.

The relation of comets to the sun's corona, the rings of Saturn, and the zodiacal light, which Dr. Weir treats with great skill and ingenuity, is to my mind the most valuable part of the book. The attempt to relate similar phenomena under one explanatory circumstance must always arouse interest, and I am sure that this part of the work will quicken thought and stimulate investigation. The argument from the probable condition of Saturn in earlier days, the effect of the currents created by its rapid revolution, together with the difference of temperature between the poles and the equator will demand attention. It is, to say the least, a reasonable explanation of the rings of Saturn. No doubt it does not wholly explain all the phenomena, but it explains more than it leaves unanswered.

The inquiry into the constitution and form of comets led Dr. Weir to the important subject of the sun. It was felt by him that there was an intimate connection between corona and comets.

The chapter on the history of Solar Research, though at first sight not intimately connected with the theory which Dr. Weir propounds, is necessary as an indication from the writer's standpoint of the inadequacy of most theories to explain solar phenomena.

Especially is the section dealing with the corona to be commended. For this portion of the inquiry the student should familiarise himself with Dr. Weir's arguments. They are worthy of consideration.

Chapter V is the centre of the investigation regarding the relation of comets, especially as regards their tail, to the outer envelope of the sun and expresses the mind of the writer very clearly.

I would commend this little book. Apart from its own intrinsic merit it is worthy of consideration as the work of one who gave up much time and thought to a branch of astronomy that has always claimed students because of its interest and importance.

ALEX. WM. ROBERTS.

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Erratum

P. 56, lines 16 and 19, *for* 'Peak' *read* 'Peek.'

INTRODUCTION

ON account of their unusual form and their appearance in the sky at irregular intervals of time, comets have always attracted a great amount of interest among the general public, and no department of astronomy has elicited more scientific research and speculation. The majority of them are telescopic objects. Many are opaque bodies and some are transparent nebulous globes.

Owing to the number of physical conditions present in comets and their peculiar combination, the elucidation of them has been attended with difficulty. This is evident from the review by Mr. Proctor of the theories which have been formulated to account for the formation of the tail. It also appears in the statement by Sir Norman Lockyer in the course of maintaining his Collision theory, and in the explanation of the solar ray theory by Mr. Maunder, as quoted by Mr. Chambers. A number of comets have been specially notable, but the one of chief interest, historically and astronomically, is Halley's comet.

In the year 1909 widespread interest prevailed both among astronomers and the intelligent general public regarding Halley's comet on account of its expected periodic return the following year. In different countries balloons and jars for the collection and analysis of cometary material were being prepared, and the American Bureau of the Astronomical and Astrophysical Sciences issued a circular regarding the phenomena to be observed. In the course of the investigation regarding the nature of comets it was noted that some eminent astronomers suggested that there was a similarity between the structure of comets' tails and such phenomena as the sun's corona and the zodiacal light; and that these varied with the waxing and waning of the sun-spot cycles, becoming most conspicuous at the time of the sun-spot maxima. This originated an inquiry regarding the constitution of the sun which is the most conspicuous object in the sky. Without the

light and heat derived from this luminary, animal and vegetable life would soon cease on the earth. To science from the earliest times the sun has been a special object of research and speculation ; and has attracted the observation of such men of renown as Galileo and Kepler, Laplace and Lagrange, Delisle and Piazzi, Newton and Halley, and the two Herschels, besides a great array of eminent astronomers and scientific workers in every part of the world. One of these, Sir Robert Ball, remarked, ‘ His splendid brilliance gives him the pre-eminence over all other celestial bodies.’ Professor Young wrote as follows : ‘ It is true from the highest point of view, the sun is only one of a multitude, a single star among millions—thousands of which most likely exceed him in brightness, magnitude, and power. He is only a private in the host of heaven. But he alone among the countless myriads is near enough to affect terrestrial affairs in any sensible degree, and his influence upon them is such that it is hard to find the word to name it; it is more than mere control and dominance. He does not, like the moon, simply modify and determine certain more or less important activities upon the surface of the earth, but he is almost absolutely in a material sense the prime mover of the whole.

‘ But while the material supremacy of the sun has always been recognised by thoughtful minds, and has even been made the foundation of religious systems, as with the Persians, it has been reserved for modern times and to our century to show clearly, just how, in what sense, and how far the sunbeams are the life of the earth and the sun himself the Vicegerent of the Deity.’ To aid the scientific investigation of the sun various instruments have been invented of which the telescope is the most conspicuous. For a full account of these reference may be made to Mr. C. G. Abbot’s book ‘ The Sun.’ Astronomers have thus been able to determine the sun’s distance from the earth, his diameter, density, light and heat-giving powers, to a certain extent his chemical composition, and other particulars. Investigation became specially active as a result of Schwabe’s discovery of the periodicity of sun spots in the year 1843, and knowledge of the phenomena presented by the sun increased so rapidly that it was considered advisable to form an international Solar Union with the object of arranging and utilising to the best advantage the knowledge gained.

The results of the investigation regarding the nature of comets and the

constitution of the sun as submitted in the following pages may be worth the consideration of those who are interested in the advancement of this department of astronomical science. My attention was directed to the question of the structure of comets and their tails by an article on the comet which appeared in the *Lovedale Christian Express* from the pen of Senator A. W. Roberts, D.Sc., F.R.A.S., and to him I owe my best thanks for subsequent perusals of the manuscripts, for gifts of valuable astronomical books, for the Foreword, and many kind and useful suggestions. I am indebted to Mr. Bain (Inspector of Schools) for remarks on the direction of the tail in comets; to the Rev. F. Jones for the loan of books; to the late Mr. A. S. Hough, F.R.S., F.R.A.S., Astronomer at the Cape, and to Mr. Wesley, Assistant Secretary of the Royal Astronomical Society, for copies of photographs. I have received the kind permission of the Astronomer Royal, Sir Frank W. Dyson, and of Dr. George Ellery Hale to make use of copies of photographs taken respectively at the Greenwich and Mount Wilson Observatories. The Oxford Clarendon Press has given permission to use certain drawings appearing in the late Mr. Chambers' book on Comets, and I am kindly permitted by Mr. R. T. A. Innes, Union Astronomer of South Africa, to include in this book portions of his circulars on Halley's comet.

JOHN W. WEIR.



HALLEY'S COMET, MAY 11, 1910 (45 m. exp.).

Taken with Astrographic Telescope.

[Kindly contributed by the Astronomer at the Cape, the late A. S. Hough, Esq., F.R.S., F.R.A.S.]

COMETS AND THE SUN

SECTION I—COMETS

CHAPTER I

ASTRONOMICAL THEORIES

VARIOUS theories have been formulated regarding comets, especially with the object of explaining the mode of formation of the tail, and a notice of these is necessary for a proper understanding of a new theory.

The Solar Ray Theory.

This was first enunciated by Kepler on observing the direction of the tail in the comet of the year 1607, subsequently known to be Halley's comet. It was accepted by Euler, Laplace and other astronomers, and has prevailed with slight modifications to the present time. According to this theory, the solar rays acting on certain material in the head of a comet as a repulsive force drives it away in the line of the radius vector, thus producing the luminous tail.

It appears in its modern form, as stated by certain astronomical authorities, as follows. Sir Norman Lockyer, referring to the memoir by MM. Faye and Roche, remarks ('Meteoritic Hypothesis,' p. 163): 'M. Faye has more recently held that this repulsive action is due to the radiant energy of the sun, and that it has an intensity inversely as the square of the distance, and proportional to the surface and not to the mass of the moving particles. Its action would therefore be in the inverse ratio of the density of the particles upon which it acted; it would vary with every difference of

cometary constitution ; it would be inappreciable on the nucleus itself (the idea being that the nucleus is a solid body) and it would be most effective in the case of the rarest vapours. The important part of M. Roche's later memoir consists in testing these views of repulsion to determine whether the forms of comets could be explained by its introduction. One result is very striking : the tail towards the sun demanded by gravitation alone at once disappears. The limiting surfaces which Roche's calculations require are so very like some of the surfaces actually observed in the head of a comet, where they can be best seen, that it is suggested that the movement of the particles takes place in the precise direction where they would flow according to M. Roche's mathematical investigations. Hence we are justified in attributing many cometary phenomena to the flow of matter acting under the influence of attraction and solar repulsion ; and in concluding his memoir Roche points out (1,393) that the hypothesis of a repulsive force acting along a radius vector and varying inversely as the square of the distance and only acting on matter reduced to a state of great tenuity gives figures identical with those observed.'

Mr. Chambers, after giving an account of the theory, remarks as follows : 'Maunder has summarised the question of both the head and of the tails of comets in a way which seems to represent all that is really known. He says, "Though the bulk of comets is huge they contain extraordinarily little substance. Their heads must contain some solid matter, but is probably in the form of a loose aggregation of stones enveloped in vaporous material. . . . As the comet gets close to the sun its head becomes heated, and throws off concentric envelopes, much of which consists of matter in an extremely fine state of division. Now it has been shown that the radiations of the sun have the power of repelling matter, whilst the sun itself attracts by its gravitational force. But there is a difference in the action of the two forces. The light-pressure varies with the surface of the particle upon which it is exercised : the gravitational attraction varies with the mass or volume. If we consider the behaviour of very small particles, it follows that the attractions due to gravitation (depending on the volume of the particle) will diminish more rapidly than its surface. A limit therefore will be reached below which the repulsion will become greater than the attraction. Thus for particles less than the $1/25000$ th part of an inch in a diameter, the

repulsion of the sun is greater than its attraction. Particles in the outer envelope of the comet below this size will be driven away in a continuous stream, and will form that thin luminous fog which we see as the comet's tail."'

Mr. Herbert Spencer Jones, lately appointed Astronomer at the Cape, in his book published in 1922, after giving an account of the theory of repulsion due to the sun's electric field, as completed by Professor Bredichin, makes the following remarks : 'More modern views are in favour of a different theory. It was shown theoretically by Maxwell, and demonstrated experimentally by Lebedeff and by Nichols and Hall, that when light falls on a body it exerts a pressure on it. This pressure is very small and proportional to the area upon which the radiation impinges. Suppose it falls upon a small sphere near the sun : then the gravitational force of attraction on the sphere due to the sun is proportional to the cube of its radius, and therefore if the radius becomes sufficiently small it may be anticipated that the gravitational attraction will ultimately become less than the radiation pressure which is proportional to the square of the radius. Theoretical investigation shows that this would be the case if the diameter of the particle were between $1.5w$ and $0.07w$ where $1w = 1/1000$ mm. A sphere of diameter equal to the smaller of these limits would still be large compared with the size of a gaseous molecule : if therefore this theory is correct the tail of a comet is not truly gaseous in nature, but is composed of a cloud of very small discrete particles. Bredichin's three types of tails may be accounted for by supposing there are particles of three different densities. The tail of a comet accordingly appears to be composed of small particles of matter ejected from the nucleus and repelled by radiation pressure from the sun. The total matter so repelled is probably small in amount and presumably is dissipated into space.'

With reference to these explanatory statements, it is to be noted that laboratory experiments with suitable apparatus may successfully demonstrate the repulsive action of light on particles of a certain size ; but in comets the conditions are more complicated and phenomena are present not explainable by the repulsive action of light.

According to the version of the solar ray theory, as enunciated by Mr. Herbert Spencer Jones, a certain size of particle is specified as suited for the

repulsive action of light, but it would be difficult to prove that there are no articles of a smaller size present; in fact, the spectroscope has revealed the presence of gases whose molecules, according to Mr. Jones's own statement, are smaller than the smallest particles on which light would set. These must therefore have been brought there by some other force than that of light. Mr. Maunder's version of the theory seems to include all particles under $1/25000$ th part of an inch as suitable for the pressure of light which would overcome the sun's attraction. The particles of a larger size would therefore come under the attraction of the sun and their progress towards it ought to be observable, unless they were intercepted by some obstacle in their way.

In the version of the theory, as it appears in the memoir by MM. Roche and Faye, the possibility of the presence of particles of various sizes is recognised and the theory framed accordingly. With reference to this it may be remarked that it seems contrary to terrestrial experience that the solar radiation pressure should be able to eliminate the tail demanded by the gravitation of the sun; suddenly and uniformly curtail the pressure of the local light, derived from incandescence, luminous gases, and electricity radiating in all directions; at the same time with the same suddenness and uniformity overcome the dispersive action of heat, of electricity, and of the rapid forward movement of the comet; and in addition, having accomplished all this, be able to drive certain material in a fairly straight line many millions of miles away. A light-refracting, light-reflecting envelope automatically renewable from gases in the head and tail would meet the conditions and harmonise with the phenomena presented.

Electrical Theory.

When Olbers, in the course of his observations of the comet of the year 1811, discovered the presence of electricity and arranged comets in three classes according to their manifestations with reference to a repulsive force emanating from the sun, a formidable rival to Kepler's Solar Ray theory was introduced into the astronomical field. A lucid account of the rise and progress of this theory until its completion by Professor Bredichin is given by Miss Clerke. The difficulties in the way of the acceptance of this theory are similar to those met with in the solar ray theory, as there is no mention of

the forces of light and heat, and the dispersive action of these and other agents taking effect on comets. The other theories formulated, besides failing to take into account the presence of light, heat and electricity, are inadequate as explanations of cometary structures and have received little support from astronomers. These are the Collision theory of Sir Norman Lockyer, the Actinic Ray theory of Professor Tyndall, the Sea Bird analogy theory of Professor Tait and Lord Kelvin, and the Negative Shadow theory of others.

CHAPTER II

ASCERTAINED FACTS

A SHORT notice of some ascertained facts regarding comets may be useful in the explanation of a new cometary theory.

The Orbits of Comets.

The form of their orbits as a parabola or eccentric ellipse was determined by the application by Newton of his recently discovered law of gravitation to the comet of the year 1680 (Newton's comet). This was confirmed by the calculations and researches of Flamsteed and Halley regarding this comet and the one of the year 1682 (Halley's comet). To these were added the observations of Doerful of Saxony, Hevelius of Danzig, Montana of Padua, and Sir William Loüer.

Comets akin to Meteors.

Aristotle was the first to draw attention to the fact that comets are akin to meteors in their nature. This was accepted by Kepler and Newton, and our knowledge of their affinity was greatly extended by the researches of Chladni, Peters, Tempel, Adams, Schiaparelli, Sir Robert Ball, and others.

Chemical Constitution of Comets.

Sir Norman Lockyer mentions that the vapours of the following chemical elements have been revealed by the spectroscope, *viz.* magnesium, light carbon compounds, iron and sodium.

Light.

By spectroscopic and other observations the following sources of the light in comets have been noted, *viz.* the sun, incandescence, luminous gases and electricity.

Sunlight, Refracted and Reflected.

It was observed by Dr. Beyers, as recorded by Miss Clerke, that comets are capable of refracting light. Seeing that the coma is not a single thin plate through which light will pass imperceptibly, but is more or less globular in form, and varying, according to Sir Robert Ball, from 20,000 to 1,000,000 miles in diameter; if terrestrial conditions can be taken as a guide, there will be dust particles surrounded by condensed gases which may reflect a portion of the light passing through, making it observable, and producing the nebulous appearance to be seen in comets.

Reflected Sunlight.

The fact of the presence of reflected sunlight in comets was observed by Sir John Herschel, and from this he concluded that they must be 'material substance.' Dr. G. P. Bond of Harvard made a careful study of Donati's comet (1858-59) and was convinced that its light was purely reflected sunlight. In the year 1879, Professor Tait, as recorded by Sir Norman Lockyer, expressed the opinion that comets' tails shone almost wholly by reflected light. The presence of reflected sunlight has also been revealed by the spectroscope in addition to the light of incandescence of electricity and of luminous gases.

Electricity.

Electricity might be inferred to be present from terrestrial analogy. Both in its thermal and frictional form it will be in greatest strength in the neighbourhood of the nucleus, and may be communicated by minor discharges to a distance, taking the form under certain conditions of an electrical luminescence. It might have an electrolytic action, so that gases in the tail may be different from those in the head, and this effect may extend to gases in space through which the comet may pass, according to the observations of Professor Newall.

Heat.

The intensity of the heat, as estimated by Sir John Herschel and Sir Robert Ball, acting on the comets of the years 1680 and 1843, both of which

had long tails, was so great that it would have made the hardest material on the earth 'run like water.' Taking the coma of a typical comet of good size surrounding a nucleus as an example, it seems fair to assume, from terrestrial analogy and otherwise, that it will contain gases with some meteoric dust and solid particles interspersed through them. For the retention of these in globular form with a clear margin, permitting of the rapid movement of the comet through space, it seems necessary that there should be some boundary structure or envelope derived from gases.

CHAPTER III

THE NEW THEORY

To indicate the presence of this boundary structure and its accord with cometary phenomena is the essence of the new theory here presented. On the comet's approach to perihelion, the heat acting on the surface of the nucleus next to the sun, and centering round the point in line with the radius vector, rarefies the gases causing them to move primarily in the direct line to the sun. Intercepted in their progress by some form of envelope, their pressure upon it produces the conical instead of the globular shape of the coma. On the increase of the heat fresh gases may be generated and expanded. Some of these may merge into the original envelope reinforcing it, and some may return along its inner surface, continuing the coma to form the tail.

That this is what takes place is confirmed by the fact that every bright or typical comet has a coma, nucleus and tail, and no comet without a nucleus in the earlier part of its perihelion passage has a tail, that is, they seem to be distinctly connected, the connecting link in all probability being the gases and dust raised from the nucleus by heat which is the recognised gas-generating, gas-expanding agent. It is also confirmed by the observations of Sir John Herschel and others regarding the continuity of the coma and tail indicating the identity of their structure. An envelope of gaseous origin and constitution will afford by its brightness and smoothness an ideal, light-reflecting surface, and thus meet the observations of Sir John Herschel, Dr. G. P. Bond, and Professor Tait, and the revelation of the presence of reflected light by the spectroscope. Any other light-reflecting material such as condensed gases, dust and solid particles without an envelope would be scattered in the vicinity of the nucleus by the combined effect of the dispersive action of the forces of light, heat, electricity, and the rapid forward movement of the comet, effectually preventing the formation

of a tail in the line of the radius vector. An envelope, while giving direction to the various forces in action, would, by its extreme tenuity and transparency, permit of the free observation of the movements of dust and solid particles.

The actual presence of an envelope formed under slightly different circumstances appeared in the comet of the year 1882 (fig. 1) as a cigar-shaped, balloon-like body, a figure of which is given at p. 155 of Mr. Chambers' book. Incidentally it shows the continuity of the envelope with the tail to its extremity. It also shows the formation of an envelope by expanding interior gases in a direction towards the sun opposite to that along which the repulsive forces of light and electricity are supposed to act.

By the presence of an envelope certain cometary peculiarities may be reasonably explained. The anomaly of diminution in size of the head of a comet instead of expansion on the comet's approach to perihelion may be caused by the rarefied gases at the surface of the nucleus moving more rapidly in the direct line and by pressure of currents from without towards the sun than at the sides, giving the coma with its envelope a conical shape. Multiple tails, as in the comet of the year 1744 (fig. 2), may be due to the nucleus being divided into sections, each with its own envelope and tail. The sections may differ in their chemical composition and be acted on differently by the forces of light, heat and electricity, which might account for the differences in appearance presented by different tails in the same comet. The whole envelope might be cast off, as seems to have been the case in Halley's comet, at the perihelion passage when tails were seen for some days in the East after the comet had passed to the West. It might be torn into bands and streamers, which were supposed to resemble locks of hair, hence the name coma. A comet may be likened to the subsidiary shaft fitted for the ventilation of mines, the main shaft being the cold of space, and the currents issuing from the main shaft and passing along the subsidiary shaft, to the currents from the cold of space pressing on the head of the comet and passing along the tail.

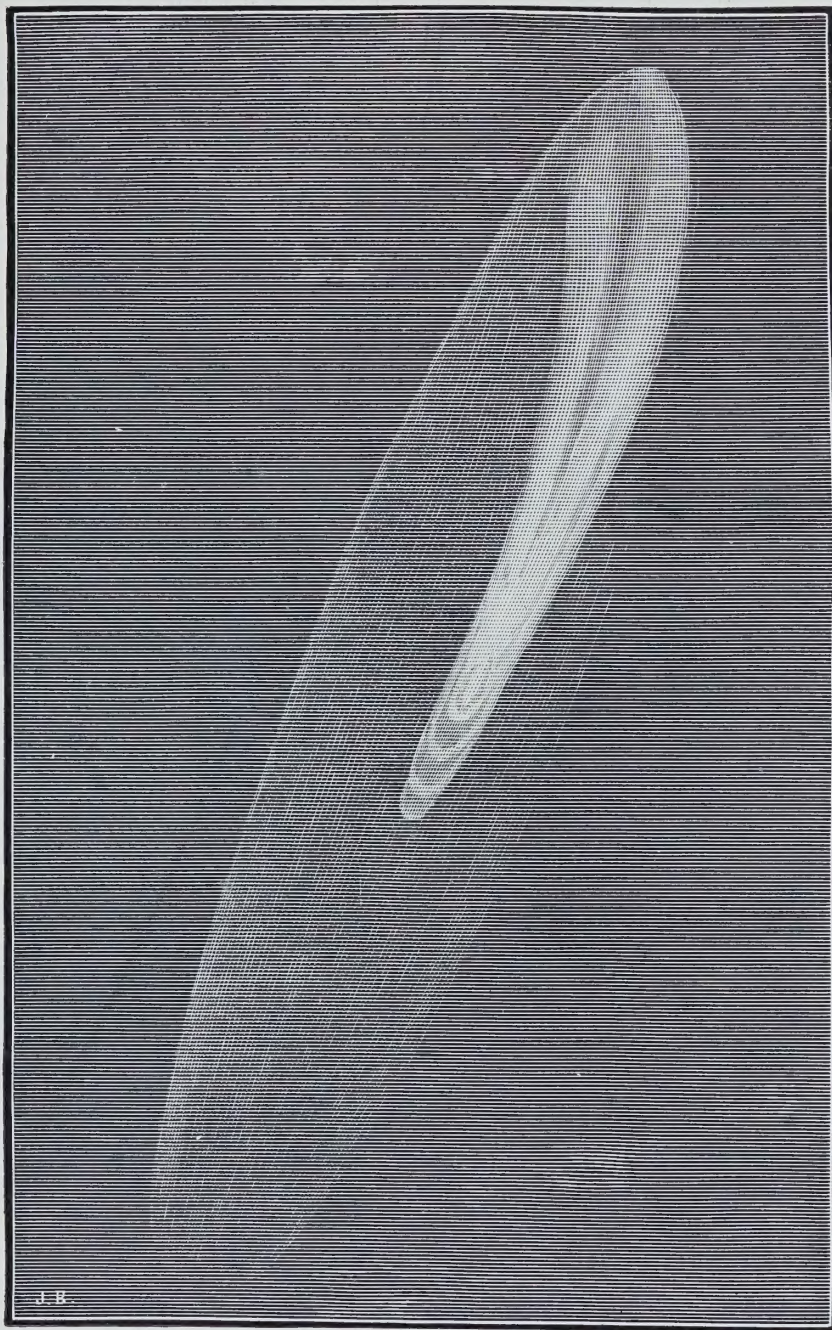


FIG. 1.—This copy of a drawing by Gen. G. H. Willis of the great comet of the year 1882 shows a distended, cigar-shaped, balloon-like envelope attached to the extremity of the tail. Its expansion has evidently proceeded from the tail and head of the comet towards the sun, that is in a direction opposite to that which is taken by the force, which according to the solar theory produces the tail, viz. the radiation pressure of the sun. Moreover, the continuity of the envelope and tail demonstrates the identity of their structure, and as an inference the validity of the envelope theory of the nature of comets' tails.

[From Chambers' 'The Story of the Comets,' by kind permission of The University Press, Oxford.]

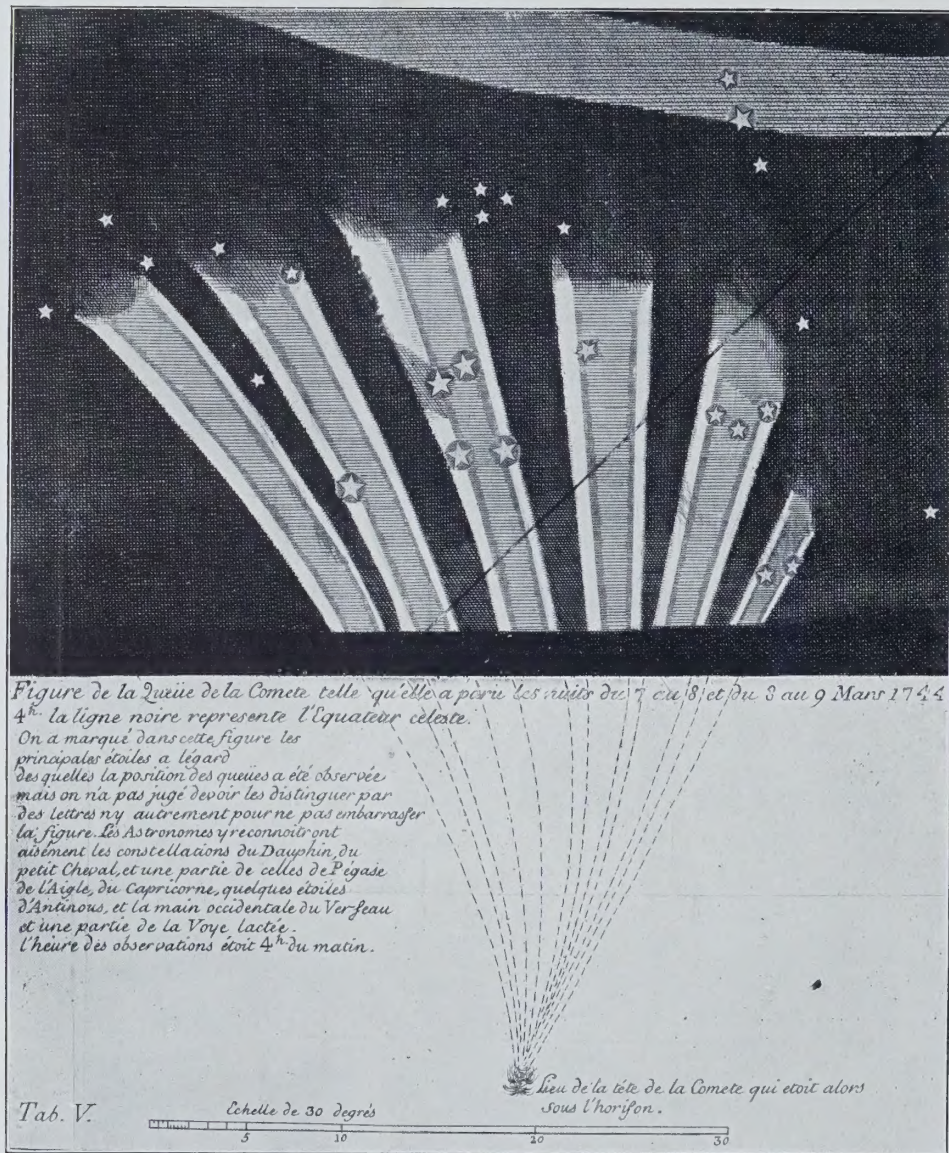


FIG. 2.—The great comet of 1744, drawn by De Chesseaux, with a number of tails each of which has a bright, clearly-defined margin. This could be ideally produced by the presence of a smooth, light-reflecting, light-refracting envelope, which would at the same time prevent the scattering of gases and dust-like material. The multiplicity of tails might be due to division of the head into sections, each of which developed a separate tail.

[From Chambers' 'The Story of the Comets,' by kind permission of The University Press, Oxford.]

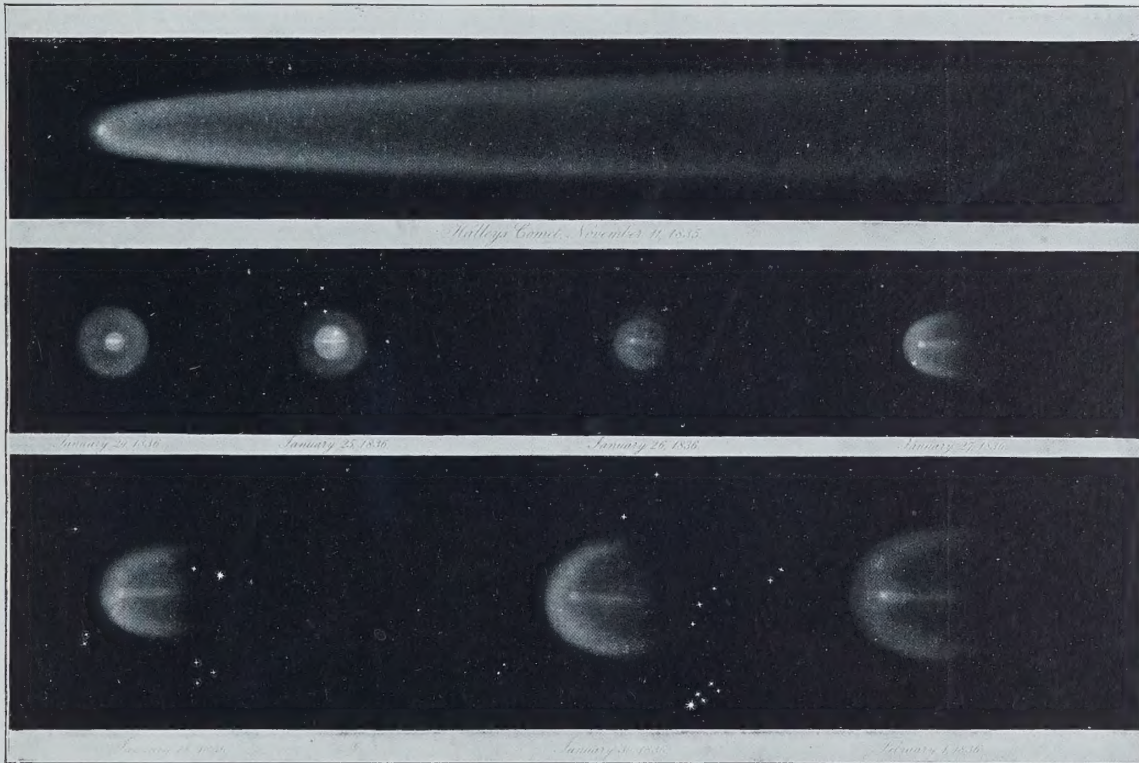


FIG. 3.—HALLEY'S COMET, 1835-36.

(Drawn by C. P. Smyth.)

Halley's Comet is shown at different stages in the course of its perihelion passage and throughout there is a clear boundary line between it and surrounding space, which could only occur under some form of envelope formation.

[From Chambers, 'The Story of the Comets,' by kind permission of The University Press, Oxford.]

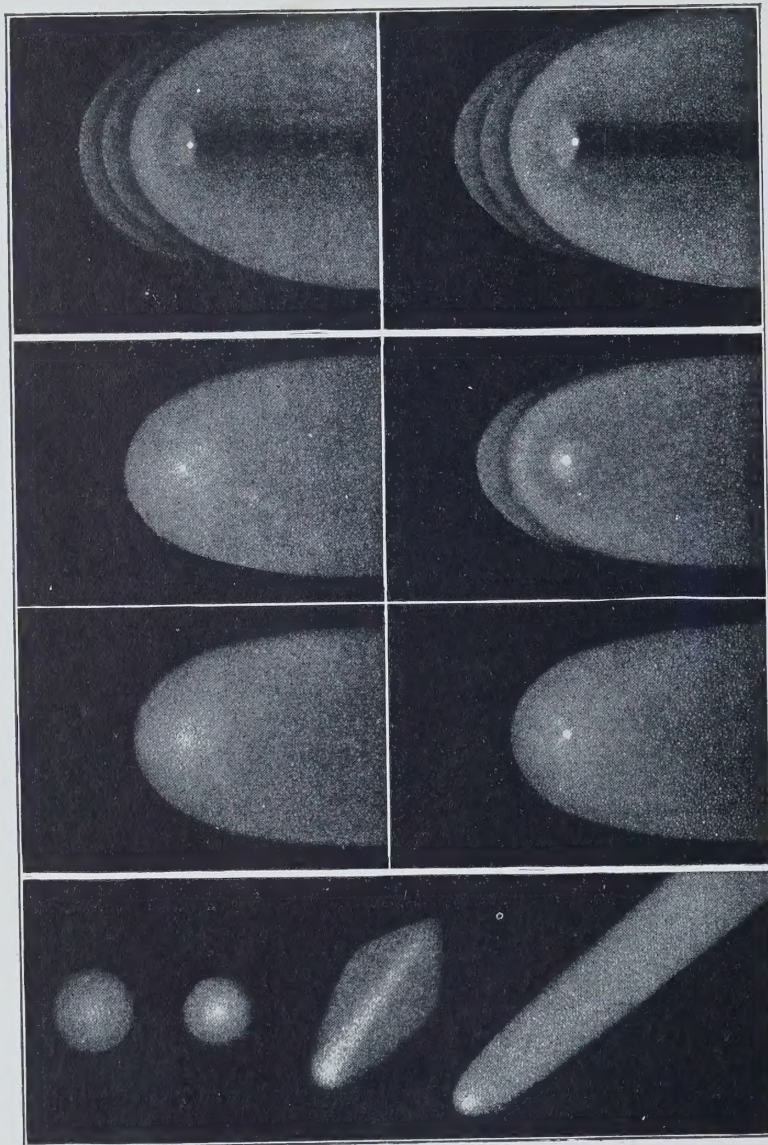


FIG. 4.—In this are shown the changes undergone by Coggia's Comet of 1874. While there is a distinctly clear margin in all the figures presented, the third from the left, bottom row, shows that this continues even with an alteration of shape probably due to external forces. The two figures on the top row show the successive formation of envelopes which might disappear or merge in the tail.

[From a drawing by W. Tempel. From Chambers' 'The Story of the Comets,' by kind permission of The University Press, Oxford.]

CHAPTER IV

KINDRED PHENOMENA

The Corona.

THE theory of a cometary envelope is supported by the corona. As an envelope surrounding the sun it is not unfamiliar to astronomers, and its affinity with cometary structures has also been suggested. Mr. Hector Macpherson, in his book 'The Romance of Astronomy' (p. 58), remarks: 'It is the final solar envelope, calm and peaceful, a fitting crown for the orb of day.' Mr. Proctor made the following observation: 'The interpretation of the coronal radiations is connected, I believe, with the subject of meteoric astronomy . . . with the phenomena of our own auroras, with the "Zodiacal Light," with cometary systems, and finally with those strange laws according to which magnetic and auroral phenomena are associated with the disturbance of the solar photosphere.' According to Professor Young spectroscopic observation reveals the presence in the corona of the following: First, incandescent dust or solid and liquid particles near the sun; secondly, gases of a permanent nature; thirdly, reflected sunlight; and fourthly, the light reflected in the earth's atmosphere. To these may be added the presence of electricity. This combination, with the exception of the light reflected in the earth's atmosphere, has also been revealed in comets, and a portion, principally reflected light and dust and solid particles, in the rings of Saturn.

The Rings of Saturn, as related to cometary appendages and a new theory of their formation.

For the double purpose of solving a hitherto unexplained problem and giving a concise elucidation of the cometary processes, note may be taken of the brief but brilliant epitome of these which occurs in the rings of Saturn, excellent drawings of which appear in the *Illustrated London News* for October 28, 1922. Of these Mr. Scrivener Bolton, who supplies them, writes as follows: 'These pictures are among the finest and most accurate that have yet appeared and are based on Professor Barnard's

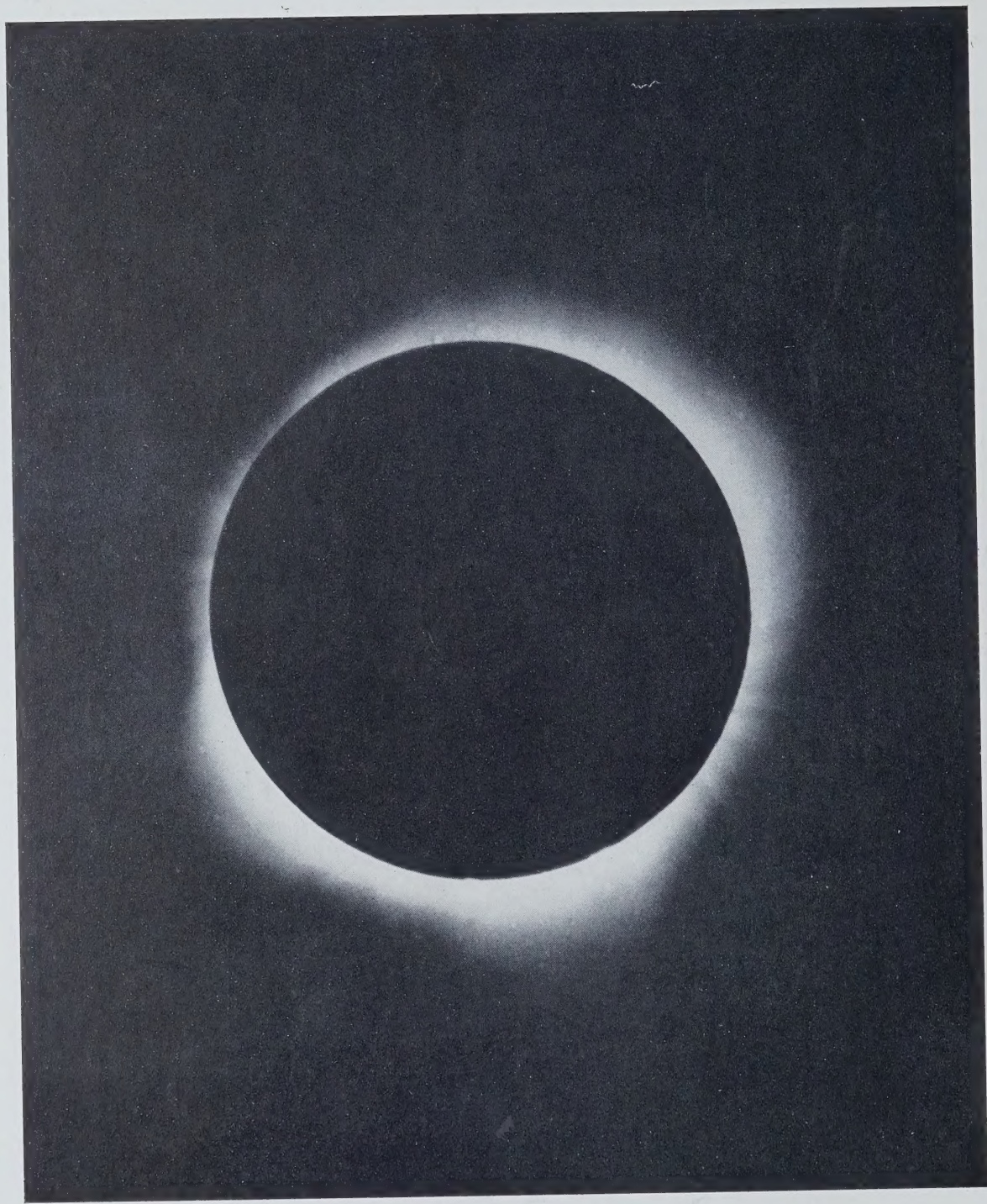


FIG. 5.—TOTAL SOLAR ECLIPSE, MAY 18, 1901 (10 sec.) (F. W. Dyson).
[By kind permission of the Astronomer Royal, Sir Frank W. Dyson.]

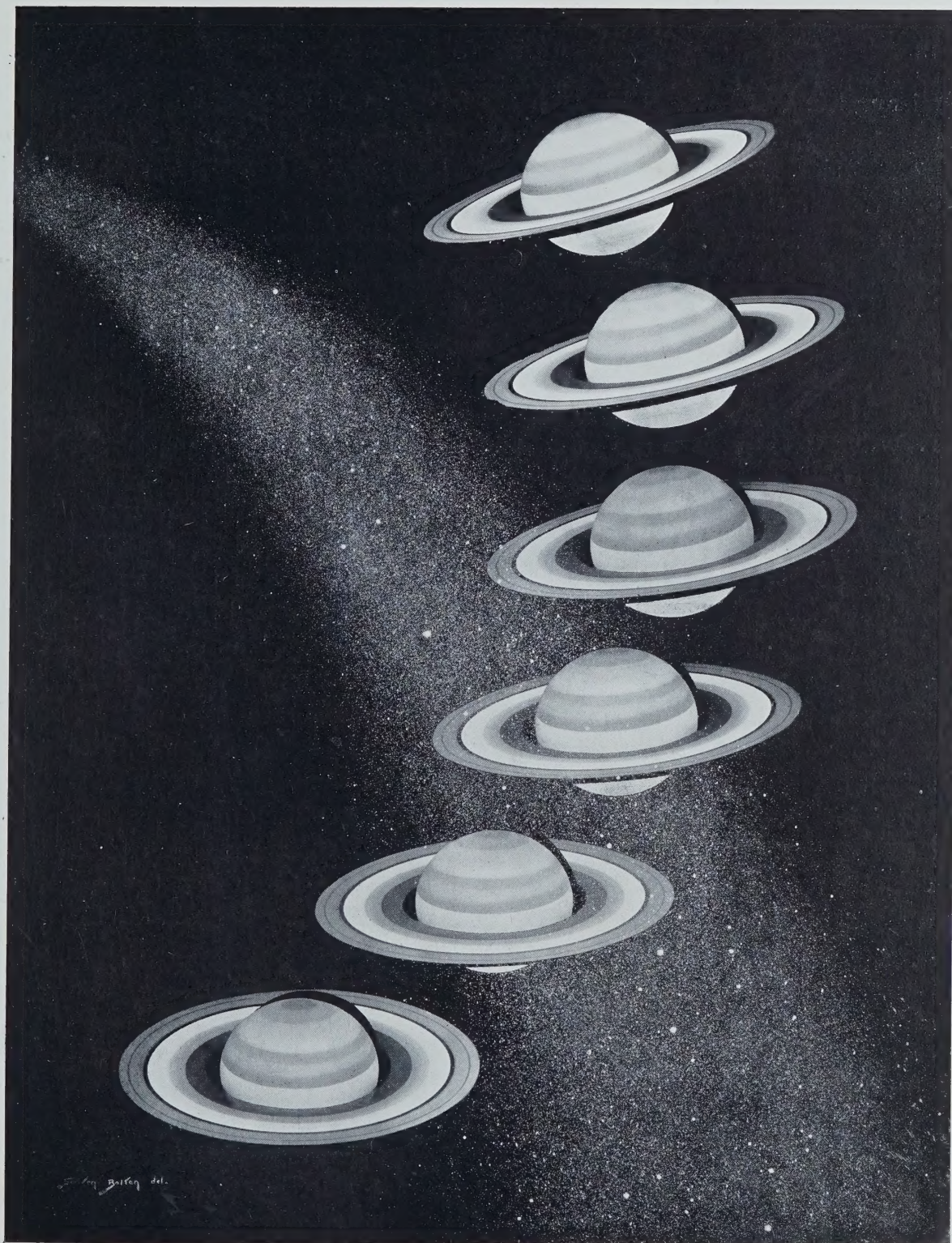


FIG. 6.—This drawing of the Rings of Saturn shows the equatorial position of the rings, and their flattened surfaces directed towards the poles, an explanation of which facts is given in the text.

[By kind permission of the *Illustrated London News*.]

micrometrical measures made with the forty-inch refractor of the Yerkes Observatory, Wisconsin, U.S.A. In the course of his article on the rings, Mr. Bolton mentions that at first they were supposed to be solid, then they were thought to be liquid. In the year 1857 Maxwell came to the conclusion that they were a vast conglomeration of solid particles moving round Saturn. Professor Keeler of the Lick Observatory verified this as correct, and calculated that the particles of the innermost ring travel at the rate of $12\frac{1}{2}$ miles per second and those of the outermost ring at the rate of 10 miles a second. He adds the remark: 'The particles are found to be smaller than was believed. In fact they range in size from a marble to an atom of dust, chiefly the latter.' Referring to the genesis of the rings, he remarks that this was ascribed by Darwin (presumably Sir George) to the breaking up of a satellite 'which was at length shattered to atoms, the particles ultimately spreading themselves uniformly round the planet.'

The difficulty raised by this theory is the elimination of the action of gravitation by which the dust and debris of a satellite would be diffusely scattered over the surface of the planet. Then, if formed, why they are not arranged over the polar magnetic axis of the primary, and why their flat surfaces are not directed East and West under its axial revolution.

I therefore venture with all deference to the great names mentioned to submit a theory which seems to obviate these difficulties. In explanation of this it is necessary again to refer to the fact that on the earth currents of air move from a locality where there is a surplus towards the centre where there is a rarefaction and deficiency caused by heat. There is thus a general tendency of the earth's atmosphere to move from the poles towards the equator, a familiar local example of which are the trade winds. In Saturn it is reasonable to suppose that at one period of the planet's history the heat of the equator was so great that gases were generated and solid particles erupted. By the continuation of the heat these would rise to a considerable distance from the whole equatorial circumference. The heat at the equator—on the supposition of the presence of an envelope surrounding the planet's atmosphere—causing rarefied gases to rise and drawing currents from its interior and from the exterior cold of space, the latter pressing on the envelope from the outside and moving with the interior currents, would force the envelope towards the equator. The strongest currents being

directed towards the source of heat at the equatorial surface, the central portions of the envelope would reach the equator before the circumferential portion, and interlacing with the envelope from the opposite side an enclosed space would be formed containing gases, dust and solid particles, and completely surrounding the equator. A continuance of the pressure from the poles on the outside of the envelope would flatten this space, and its broad surface would be directed towards the poles. By the outside currents and by the distending gases within the envelope would be raised further and further from the surface of the planet. Its movements, probably of a wavy character under these agencies, would account for the fact that by some observers the rings were supposed to be liquid, and its uniform reflection of light would give the impression of a solid body as stated by others. In the interior of the space gases, dust and solid particles could freely revolve round the planet at the rates estimated by Professor Keeler, the transparency of the envelope freely permitting of the observation of these. That other rings might be formed under a periodic increase of heat may be inferred from the conditions presented by the sun, where the periodic heat varies in harmony with the waxing and waning of the sun-spot manifestations.

The rings which rose beyond a certain distance would come increasingly under the force of the sun and be ruptured and cast off or simply vanish into outer space. Those unable to rise sufficiently far from the surface owing to a cooling process would come more and more under the attractive power of the planet. An illustration of the manner of formation of rings seems to occur in the corona. At page 64 of his book 'The Story of the Heavens' Sir Robert Ball remarks on the eclipses of the years 1867, 1878 and 1889, occurring at sun-spot minimum the corona showed long and faint streamers nearly in the direction of the sun's equator and short but distinct brushes of light near the poles. In the eclipses of 1870, 1882 and 1893, near sun-spot maxima the corona was more regular, circular, and chiefly developed over the spot zones. This would seem to indicate that in the course of time the polar corona might disappear and the equatorial streamers continue as rings. The links between the corona, the cometary appendages and the rings of Saturn would thus be complete, a light-reflecting envelope being conspicuous among the common elements of their structure.

The Zodiacal Light.

The shape and appearance of the zodiacal light is suggestive of the corona. The observations of the Rev. George Jones, made in the years 1853-55 when chaplain to the United States steam-frigate *Mississippi*, and characterised by Mr. Maunder as classic, describe the 'effulgence' which in the corona might be the light coming from the neighbourhood of the sun. The 'stronger light' and the diffuse light would correspond with the light of the corona at a distance from the sun.

SECTION II—THE SUN

CHAPTER I

THEORIES—PAST AND PRESENT

VARIOUS theories have at different times been formulated regarding the constitution of the sun. There is the theory of a central solid core of Galileo, Kirchoff, Lalande and others. Sir William Herschel on theological grounds believed that the sun was not only solid but habitable; J. F. Herman Schulz argued in favour of a sun mainly liquid, in opposition to the gaseous theory of Mr. C. G. Abbot, Professor Young and some other astronomers. Professor Young summarised his own view and that of others as follows ('The Sun.' Introduction, page 8): 'Combining the facts just stated, astronomers are for the most part agreed upon the following conclusions as to the constitution of the sun:—

'(1) The central portion is probably for the most part a mass of intensely heated gases.

'(2) The photosphere is a shell of luminous clouds formed by the cooling and condensation of the condensable vapours at the surface where exposed to the cold of outer space.

'(3) The chromosphere is composed mainly of uncondensable gases, conspicuously hydrogen left behind by the formation of the photospheric clouds and bearing something of the same relation to them that the oxygen and nitrogen of our own atmosphere do to our own clouds.

'(4) The corona as yet has received no explanation which commands universal consent. It is certainly truly solar to some extent and very possibly may be also to some extent meteoric.'

At p. 229 of the same book Professor Young takes notice of a theory lately propounded by Schmidt of Stuttgart in the following words: 'It amounts to this, that the sun is a great globe of heated transparent gas, much

denser in the centre, and the apparent definiteness of outline is due to the curious refraction of the light in such a medium.' Mr. Abbot, referring to Halm's views, remarks as follows : ' He accepts Helmholtz' hypothesis that the source of the solar energy lies in the contraction of the sun, and thinks in contradiction to See's views that the sun is gradually cooling.' Sir Robert Ball, in discussing the question, makes the following statement (' The Story of the Heavens,' p. 523) : ' There is, however, good reason to believe that the sun was once more gaseous than at present ; possibly he may at one time have been quite gaseous enough to admit of this reasoning in all its fullness. At present the sun appears to be in some intermediate stage of its progress from the gaseous to the solid conditions.'

It will be noted that the theory here submitted is in accord with Halm's observation that the sun is cooling, and with Sir Robert Ball's conclusion that the sun is passing from the gaseous to the solid condition. It further indicates to a certain extent the stage which the sun has reached in the course of its transition.

New Theory.

In framing a theory regarding the process of cooling and solidification in the sun, note may be taken of certain physical conditions which are present. From the earliest rotation of the sun round a polar axis after it has assumed a globular form there would be a slower rate of rotation and less friction with a tendency to a lower temperature at the poles than at the equator. A lower temperature will imply greater density with contraction and gravitation of the denser material towards the poles.

Rotation Periods.

The rotation periods in different latitudes are noted by Mr. Abbot as follows : ' According to the results referred to in the following table,¹ the sidereal rotation of the average solar surface is completed in about 24·6 days at the equator, 26·3 days at 30 latitude, 31·2 days at 60, and 35·3 days at 80. The agreement between Adams' and Duner's work, done in different years, is so exact that there seems little reason to suspect a secular variation of the retardation towards high latitudes.' An explanation of this may be

¹ *i.e.* A table appearing in Mr. Abbot's book.

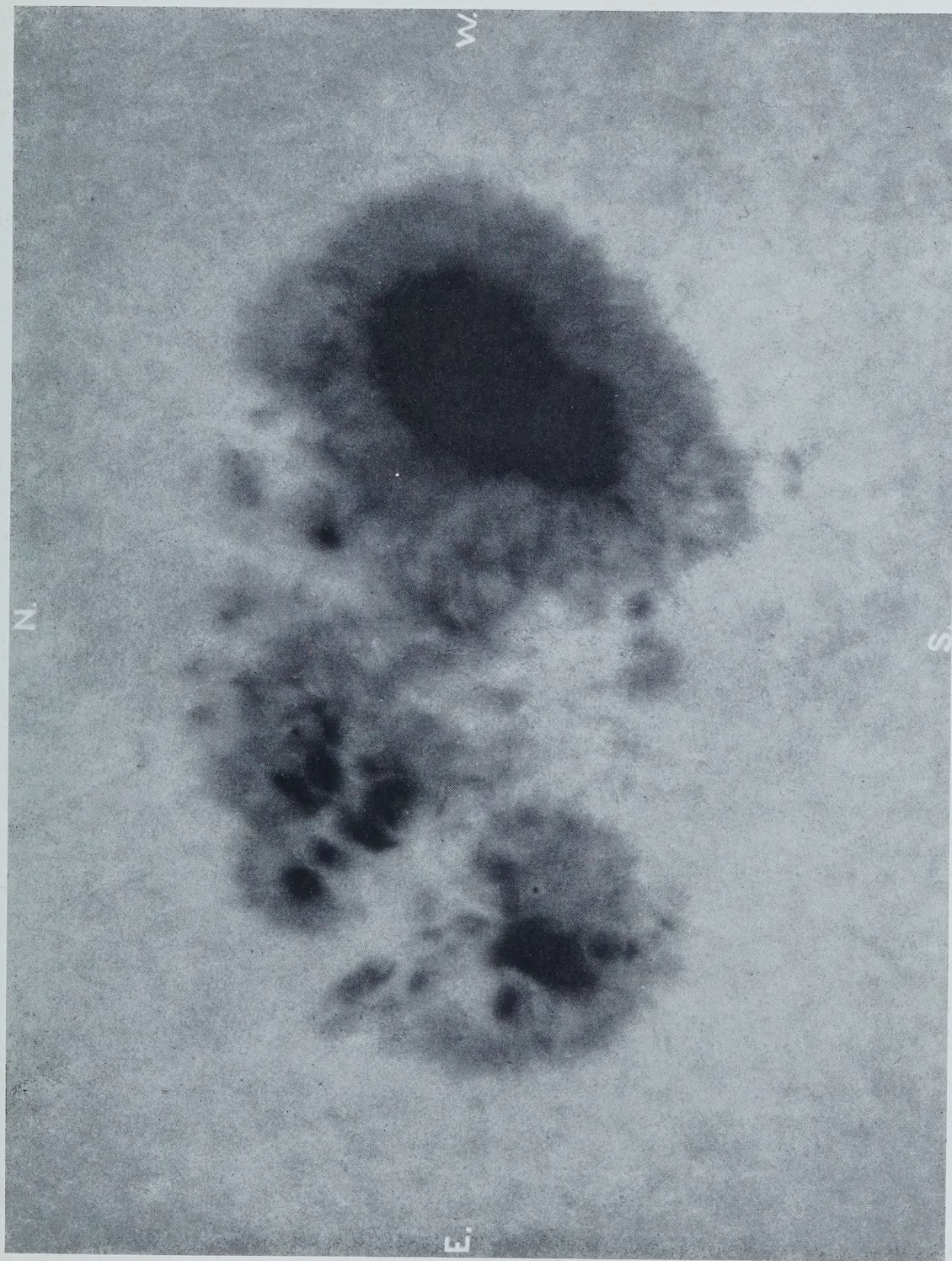


FIG. 7.—SUN SPOT, JULY 31, 1906, ROYAL OBSERVATORY, GREENWICH.
[By kind permission of the Astronomer Royal, Sir Frank W. Dyson.]

found in a difference of consistency between the equatorial photosphere and that of the higher latitudes, the former being more gaseous or fluid and the latter more viscous or solid.

The Density of the Sun.

Taking the density of the sun to be 1·4, water being 1, this would mean that the sun cannot be wholly gaseous, as its density would then be lower than water. This may also apply if the sun were partly gaseous and partly fluid, whereas if to these be added a due proportion of solid material the result would then be the density of 1·4.

On the earth molten fluids cool from without inwards, as in the familiar moulding of bullets and metal castings; and the processes of cooling and solidification are intimately associated as cause and effect. In the sun as a globe any diminution of temperature would proceed from the circumference towards the centre as well as from the poles. This would harmonise with Mr. Abbot's observations regarding the difference in brightness between the centre of the sun and the limb, which he has carefully noted with the spectroscope and bolometer and put in tabular form. At the equator the great intensity of the heat seems to preclude the inception of a cooling process, and this is in accord to that extent with the gaseous theory of the sun. Although the cooling process might be incalculably slow and the resulting material infinitesimally small and liable to be constantly reconverted into gas, it might in the course of innumerable ages attain to some quantity and assume some fluid or solid consistency, thus permitting of pressure taking effect and obviating the difficulty raised by the observation of Professor Andrews, *viz.* that gases kept at a temperature above the critical point cannot be converted into liquids under any pressure, however great, to which they might be subjected. This pressure is so great in the sun that Sir Robert Ball ('The Earth's Beginning,' p. 101) remarked as follows: 'The fact is that the terms liquids, gases, and solids cease to retain intelligible distinctions when applied to materials under such pressure as would be found in the interior of the sun.'

The cooling process may have been initiated at an early period of the sun's history, whether from a nebula or otherwise, whenever a polar axis was formed by the interaction of the forces of magnetic attraction and

repulsion, and gravitation on gases or other material. By its continuance for an incalculably long period of time the sun would ultimately assume its present well-defined form density and dimensions. At page 241 of his work, 'The Sun,' Mr. Abbot brings forward six questions for explanation, and to these he gives very weighty answers supporting the gaseous theory of the constitution of the sun. They may, however, perhaps admit of simpler replies by the acceptance of the theory here submitted of some solidification having extended from the poles to within 5 or 10 degrees on either side of the equator. Numerous openings and gaps increasing in size and number from the polar to the equatorial regions may permit of the escape of molten fluids and gases which overflow the surface obscuring telescopic observation and so radiating the heat that it is difficult to determine a difference of temperature between the several regions, even with the most delicate instruments. Mr. Abbot's questions are :

1. Why the sun presents a sharp boundary ? The solidification above mentioned would meet this.

2. Why the enormous radiation of the photosphere does not so far cool its surface as to precipitate clouds ? The reply to this is that at the poles there is sufficient cooling to produce the quiescent form of prominences which take all the forms of terrestrial clouds and which, according to Professor Young, are of local origin.

3. Why a more or less definite structure appears on the sun ? This would be the natural result of a process of cooling and solidification extending over a considerable portion of the sun, as stated in the theory now submitted.

4. Why the spectrum of the sun is mainly continuous ? As a reply to this I may be allowed to quote the words of Mr. Herbert Spencer Jones, Astronomer at the Cape. In his book, 'General Astronomy,' at p. 119, he writes the following : '3. Continuous Coloured Bands. Spectra of this type containing no dark lines are emitted by glowing solids or by glowing gases, when submitted to great pressure. The portion of the sun which has undergone solidification would represent the glowing solid.'

5. Why, towards the limb, there is a gradual decrease in brightness and an alteration in spectral distribution ? This will be the result if, as

stated in this theory, the sun is cooling from the circumference towards the centre, as well as from the poles towards the equator.

6. Why the solar spectrum has dark lines? Again I may quote the words of Mr. Herbert Spencer Jones, *viz.* : ' The fact that the solar spectrum is a dark line spectrum indicates therefore that light from the hot interior of the sun passes through a layer of lower temperature at the sun's surface. The elements in this lower temperature layer can be identified from the position of the lines in the spectrum.' In other words, there is a cooling of gases at the surface in order to produce this lower temperature layer and the light from the solidified material being kept hot from within, or from compressed gases passes through this lower temperature layer and gives a spectrum with dark lines.

An investigation regarding the nature of the constituent solar phenomena seems to confirm very strongly the account here given of the transition that is taking place.

CHAPTER II

SOLAR PHENOMENA. SUN SPOTS

Sun Spots.

AN important part of solar research has been directed to the study of sun spots. Dark spots in the sun were seen with the unaided eye in China as early as the year 607 B.C. In recent times they have been noticed on several occasions by Mr. Maunder, as recorded in his book, 'The Heavens and their Story.' With the aid of the telescope (invented in Holland about the year 1608 or 1609) the great Italian astronomer, Galileo, using an instrument of his own make, observed spots on the sun about October 1610. In the same or the following year they were seen by the German astronomers Fabricius and Scheiner. Since then, but especially since the discovery of their periodicity by Schwabe in the year 1843, they have been objects of great interest and constant telescopic observation. Their appearance has been minutely described, and their size, situation, number, mode of distribution and rates of rotation in different latitudes carefully noted. In appearance they are described as dark objects, usually roundish in form with a black centre, the 'nucleus' or 'umbra' and a lighter margin the penumbra, presenting the appearance of rays surrounding the nucleus. In giving an account of their size Mr. Maunder remarks ('The Heavens and their Story,' p. 141): 'The smallest spot we measure would be about the size of Russia, Poland and Finland together; into the larger spots might be poured worlds like ours, as peas are poured into a saucer.' Their situation and mode of distribution is a point of importance, and on this the observations of some recognised astronomical authorities may be quoted. Sir Robert Ball observes ('The Story of the Heavens,' p. 39): 'The sun spots do not occur at all parts of the sun's surface indifferently. They are mainly found in two zones on each side of the solar equator, between the latitudes of 10 degrees

and 30 degrees. On the equator the spots are rare, except curiously enough when there are few spots elsewhere. In high latitudes they are never seen. Closely connected with these peculiar principles of their distribution is the remarkable fact that spots in different latitudes do not indicate the same values for the period of rotation of the sun. By watching a spot near the sun's equator, Carrington found that it completed a revolution in twenty-five days and two hours. At a latitude of 20 degrees the period is about twenty-five days and eighteen hours, at 30 degrees it is no less than twenty-six days and twelve hours, while the comparatively few spots observed in the latitude of 40 degrees require twenty-seven and a-half days to complete their circuit.' Mr. C. G. Abbot, Director of the Smithsonian Astrophysical Institution at Washington, states: 'Sun spots very seldom occur at higher latitudes than 40 degrees. Within the sun-spot belt 80 degrees as thus defined the distribution of spots is irregular. . . . There seems to be a close connection between the latitudes of great prevalence and the periodicity of sun spots.' Young states the matter as follows: 'Speaking broadly, the disturbance which produces the spots of a given sun-spot period first manifests itself in two belts about 30 degrees north and south of the equator. These belts then draw in toward the equator and the sun-spot maximum occurs when their latitude is about 16 degrees, while the disturbance gradually and finally dies out at a latitude of 8 degrees or 10 degrees, some twelve or fourteen years after its first outbreak. Two or three years before this disappearance, however, two new zones of disturbance show themselves. Thus at the sun-spot minimum there are four well-marked spot belts, two near the equator due to the expiring disturbance, and two in high latitudes due to the newly beginning outbreaks, and it appears that the true sun-spot cycle is from twelve to fourteen years long, each beginning in high latitudes before the preceding one has expired near the equator.'

In a summary of the results of solar observations made at Greenwich from 1874 to 1902 the Astronomer Royal, Christie, shows the prevailing latitudes in which spots appeared in different stages of the sun-spot cycles. 'The maximum latitude at which spots occurred was 42 degrees, but they could only be regarded as sporadic phenomena above latitude 33 degrees. Preceding a time of sun-spot minimum the prevailing spottedness occurred at low latitudes and when the spots reappeared after minimum it was



FIG. 8.—SUN-SPOT VORTICES, OCTOBER 7, 1908. (G. E. Hale.)
[By kind permission of Dr. George Ellery Hale.]

generally at high latitudes. The equatorial belt from 5 degrees to 5 degrees was never a centre of spottedness.'

Theories.

Various theories have at different periods been formulated to account for the nature and origin of spots. They were at one time supposed to be planets moving round close to the sun, a theory which was maintained by Scheiner and supported by the French astronomer Tardé, who named them Bourbonian stars as a compliment to the Bourbonian reigning family. It was refuted by Fabricius and Galileo, who observed that they were objects situated on the surface of the sun. Galileo himself formed the opinion that they were clouds closely connected with the sun. This view was adopted by Kirchoff and in a modified form by Derham, Capocci and Peters, who supposed the clouds to be the eruptive products of solar volcanoes.

In the year 1769 Dr. Wilson, Professor of Astronomy, read a paper at a meeting of the Glasgow Philosophical Society in which he advocated the theory that they were cavities in the body of the solid sun, mainly because it was the eastern side of the spot which came first into view as it moved round with the sun, and the western which disappeared last. Lalande, on the other hand, vehemently opposed this view, and maintained that they were solar mountains projecting above the surface of the sun. Sir William Herschel's theory was that they were openings in the solar clouds caused by forces from below, and that through the openings there could be seen the dark solid sun below. Sir John Herschel came to the conclusion that the openings in the clouds were caused by great stormy currents penetrating downwards instead of upwards and producing the dark appearance of the spots. In 'Familiar Lectures on Scientific Subjects' (p. 81), he expresses his view as follows: 'I must now proceed to tell you what the telescope has revealed to us as to the nature and magnitude of these spots. And here again the closer we look the more the wonder increases. The spots were at first supposed to be clouds of black smoke floating over the great fiery furnace beneath them, then comets fallen in to feed the fire, then tops of mountains standing up, a great surging ocean of molten matter. They are none of all these things, they are not clouds floating above the light, nor protuberances sticking up above general surface, they are regions which

by the action of some most violent cause the bright luminous clouds or what at all events we may provisionally call clouds which float in the sun's atmosphere are for a time cleared off, and through the irregular vacuities thus created allow us to see perhaps thousands or tens of thousands of miles below them first a layer of what we may consider real clouds which appear comparatively dark as if they were not self-luminous but were seen only by the reflected light of the upper layer of bright ones ; secondly, through other openings in this first layer a second still darker layer, independent of the first and probably still thousands of miles below that and reached by some but very little light from above ; and, thirdly, through again other openings what at present we must consider to be the body of the sun itself at some vast and immeasurable depth still lower—and emitting so little light in comparison as to appear quite black though that does not prevent them from being in as vivid a state of fiery glare as a white hot iron ; when we remember what has been said of the limelight appearing black against the light of the sun's surface. And it is a fact that when Venus and Mercury pass across the sun and are seen as round spots on it they do really appear sensibly blacker than the blackest parts of the spots.' More recently Sir Robert Ball ('The Story of the Heavens,' p. 67) remarks : 'With regard to the nature of sun spots the idea first suggested by Secchi and Lockyer that they indicate down rushes of cooler vapours into the photosphere (or its surface) seems on the whole to accord best with the observed phenomena. We have already mentioned that the spots are generally accompanied by faculæ and eruptive prominences in their immediate neighbourhood, but whether these eruptions are caused by the downfall of the vapour which makes the photospheric matter splash up in the vicinity, or whether the eruptions came first by diminishing the upward pressure from below form a "sink" into which overlying cooler vapour descends are problems as to which opinions are still much divided.' Professor Young, after discussing the various sun-spot theories, among the most recent being those of Faye and Secchi, Lockyer and Schaeberle, remarks as follows ('The Sun,' p. 187) : 'The writer some time ago suggested a modification of Secchi's theory which seems to remove some of the objections, and appears on the whole more probable than any of the others. It may be that the spots are depressions in the photospheric level caused not directly by the pressure of the erupted materials from above

but by the diminution of the upward pressure from below, in consequence of eruptions in the neighbourhood; the spots being, so to speak, sinks in the photosphere. Undoubtedly the photosphere is not a strictly continuous shell or crust, but it is heavy as compared with the condensed vapours in which it lies just as a rain cloud in our terrestrial atmosphere is heavier than the air, and it is probably continuous enough to have its upper level affected by any diminution of pressure from below. . . . Putting these things together it would seem that, whenever a free outlet is obtained through the photosphere at any point thus decreasing the inward pressure, the result would be the sinking of a portion of the photosphere somewhere in the immediate neighbourhood to restore the equilibrium and if the eruption were kept up for any length of time the depression in the photosphere would continue till the eruption ceased. This depression filled with overlying gases would constitute a spot. . . . So far as we know the spectroscopic and visual phenomena, none of these contradict this hypothesis. As regards the limitation of the spots to certain latitudes this, as has been said already, almost certainly will find its explanation in that of the equatorial acceleration. Faye, Bopolsky, Lockyer, and Schaeberle all present such explanations.' In considering the question it is to be noted that Professor Young, representing a number of astronomers, does not state in what way 'the limitation of the spots to certain latitudes will find its explanation in that of the equatorial acceleration.'

In like manner neither did Lalande in his theory of solar mountains, nor does Mr. Abbot in his theory of 'vortices,' explain the cause of the absence of sun spots from the poles and from the equator. None of the theories give an explanation of the periodic appearance of the sun spots, and their movement towards the equator usually ceasing altogether from five to ten on either side of the equator itself, or for the different rates of their rotation round the sun in different latitudes.

Secondly, it is a noteworthy fact that some eminent astronomers arrived at the conclusion that there was some solidity in them. Lalande formed the opinion that they were solar mountains, and Mr. Maunder on account of their movements called them 'solar shales.' Thirdly, there is the observed fact that the periodic outbreaks of the spots begin in the higher, colder latitudes. Fourthly, there is the observation of Professor G. E. Hale and others that the spots are cooler than the surrounding

photosphere, and that is this which gives them their dark appearance, although in reality they may be red or white hot.

Taking terrestrial conditions as a guide, it is a familiar fact that the processes of cooling and solidifying of molten liquids are intimately connected as cause and effect. As this will obtain throughout nature it will hold true in the sun if the conditions are otherwise favourable. In the sun spots there is the fact of a cooler temperature observed by some astronomers and the opinion that there is some form of solidity in them held by others. Thus it does not seem altogether unreasonable to suppose that the sun spots are the results of a cooling and solidifying process operating in the sun, the former being connected with the latter as cause and effect. If this be so, the double process must be in action somewhere, in some latitude or other of the sun, which might perhaps be approximately determined. As previously stated, certain facts indicate the possibility of a cooler temperature at the poles of the sun than at the equator, and on the earth the cooling of molten fluids extends from the without inwards. There is thus a double direction in which to look for these processes in the sun. The fact that the several outbreaks of sun spots at successive periods begin in the higher latitudes is another inducement to have the attention directed to the polar regions. It is a noteworthy fact that in the immediate neighbourhood of the poles the uniformity of the surface is not broken by the appearance of faculæ, spots or eruptive prominences, and it seems allowable to suppose that here the cooling, solidifying process advancing from two directions, *viz.* from the poles towards the equator and from the surface towards the interior acting in combination, have been able to produce solidifying material sufficient in quantity and consistency to resist the explosive and other forces which produce these phenomena. And if that be so, it seems reasonable to infer that from time to time these forces may, to a certain extent, gain the ascendancy, and a proportion of solidifying substance be reconverted into liquid and gas. On the other hand, fragments of material might be detached and either sink towards the poles, there to strengthen the cooling, solidifying mass, or be carried towards the equator and unite with other fragments to form large masses. These might assume a more or less rounded form by movement in a boiling molten sea, and perhaps acquire a fused surface of considerable depth and resisting power. If, then, the equatorial, solidifying process be much less advanced than the polar, and there be only

a thin layer of viscous or semi-solid material produced by the surface cooling, the 'slag' of Zollner, the more solid rounded masses from the higher latitudes might be driven from below by some great expansion or explosion of liquid or gas against its under surface. The effect would be to raise the surface material into the bright areas and luminous hillocks included under the term *faculæ*; a transition stage from these to the sun spots appears to be the veiled spots first described by Trouvelot in the year 1875.

Gravitation acting on solidifying masses derived from the higher latitudes would draw these towards the centre of the sun, where the enormous volume of gases compressed to an inconceivable degree would furnish ample material and force for explosions. That these may occur in connection with sun spots is evidenced by the event which happened in the year 1859. Sir Robert Ball quotes the following account given of it by Professor Young: 'One of these events has become classical. It occurred on the forenoon (Greenwich time) of September 1, 1859, and was independently witnessed by two well-known and reliable observers—Mr. Carrington and Mr. Hodgson—whose accounts of the matter may be found in the *Monthly Notices of the Royal Astronomical Society* for November 1859. . . . They simultaneously saw two luminous objects, shaped something like two new moons, each about 8000 miles in length and 2000 wide, at a distance of some 12,000 miles from each other. These burst suddenly into sight at the edge of a great sun spot with a dazzling brightness at least five or six times that of the neighbouring portions of the photosphere, and moved eastward over the spot in parallel lines, growing smaller and fainter, until in about five minutes they disappeared, after traversing a course of nearly 36,000 miles.' The eruptive prominences, some of which move with a velocity of over 100 miles a second and usually associated with sun spots, are also evidence of the presence of great explosive forces.

If we suppose a mass continuing to rise from below either gradually or suddenly openings would be formed in the surface solidifying layer, and these would increase in size until the appearance of the main body, when this layer torn into bright filaments adhering to the sides of the dark mass would constitute the penumbra, and these might be twisted about by electrical and gaseous explosions as observed by Dr. Peters. The observations of Fox regarding the phenomena occurring previous to the appearance of a spot, and the following very graphic description of the formation of a spot by

Professor Young ('The Sun,' pp. 122-123), confirms the view here enunciated regarding the nature and origin of a spot. 'There is no regular process for the formation of a spot, sometimes it is gradual, requiring days or even weeks for its full development and sometimes a single day suffices. Generally for some time before the appearance of the spot there is an evident disturbance of the solar surface manifested especially by the presence of numerous and brilliant faculæ, among which pores or minute black dots are scattered. These enlarge and between them appear greyish patches apparently caused by a dark mass lying veiled below a thin layer of luminous filaments. The veil grows gradually thinner and vanishes giving up at last the completed spot, with its perfect penumbra. The "pores" some of them coalesce with the principal spot, some disappear, and others "constitute" the attendant train. When the spot is once completely formed it assumes usually an approximately circular form and remains without striking change until its dissolution. As its end approaches, the surrounding photosphere seems to crowd in upon and cover and overwhelm the penumbra. Bridges of light often many times brighter than the average of the solar surface push across the umbra, the arrangement of the penumbra filaments becomes confused, and, as Secchi expresses it, the luminous matter of the photosphere seems to tumble pell-mell into the chasm which disappears and leaves a disturbed surface marked with faculæ which in their turn subside after a time. As intimated before, however, the disturbance is not infrequently renewed at the same point after a few days and a fresh spot appears where the old one was overwhelmed.' At page 187 of his book, after referring to some of the theories formulated, Professor Young remarks: 'It would seem easy to decide the question by observation, but it does not appear to be so; on the whole, however, the weight of the evidence is pretty strongly in favour of the opinion that faculæ and pores and a general disturbance of the region are usually obvious before the spot manifests itself, and it must be admitted that in some cases the appearances puzzlingly resemble the emergence of a dark mass from beneath.'

The different rates of rotation of sun spots in different latitudes seems to indicate a variation in the consistency of the material of the photosphere, the equatorial being the more fluid. This would support the argument in favour of some form of polar solidification.

CHAPTER III

THE SOLAR PROMINENCES

THESE are notable solar phenomena and are of two forms, the eruptive and the quiescent. In his book, 'The Sun,' p. 218, Professor Young gives the following account of them : ' In their form and structure the protuberances differ as widely as in their magnitude. Two principal classes are recognised by all observers, the quiescent cloud-formed or hydrogenous, and the eruptive or metallic. By Secchi they are each subdivided into several sub-classes or varieties, between which, however, it is not always easy to maintain the distinctions. . . . The quiescent prominences in form and texture resemble with almost exactness our terrestrial clouds and differ among themselves as much and in the same manner. The familiar cirrus and stratus types are very common, the former especially, while the cumulus and cumulostratus are less frequent. The protuberances of this class are often of enormous magnitude especially in their horizontal extent, but the highest elevations are attained by those of the eruptive order, and are comparatively permanent, remaining for hours and days without serious change ; near the poles they sometimes persist through a whole solar revolution of twenty-seven days. . . . The genesis of this sort of prominence is problematical. They have been commonly looked upon as the debris and relics of eruptions consisting of gases which have been ejected from beneath the solar surface and then abandoned to the action of the currents of the sun's upper atmosphere. But near the poles of the sun, distinctively eruptive prominences never appear and there is no evidence of aerial currents which would transport to these regions matter ejected nearer the sun's equator. Indeed the whole appearance of these objects indicates that they originate where we see them. Possibly, although in the polar regions there are no violent eruptions, there yet may be a quiet outpouring of heated hydrogen sufficient



THE GREAT SCARLET SOLAR PROMINENCES, WHICH ARE SUCH A NOTABLE FEATURE OF THE SOLAR PHENOMENA, ARE IMMENSE OUTBURSTS OF FLAMING HYDROGEN RISING SOMETIMES TO A HEIGHT OF 500,000 MILES,

to account for their production—an outrush issuing through the smaller pores of the solar surface which abound near the poles as well as elsewhere.' The eruptive prominences are of a different order, and consist of material ejected with great force from the interior of the sun. They thus correspond not to terrestrial clouds but to volcanoes. Professor Young, in his book 'The Sun,' gives the following vivid account of them: 'The eruptive prominences are very different—much more brilliant and much more vivacious and interesting. They consist usually of brilliant spikes or jets which change their form and brightness very rapidly. For the most part they attain altitudes of not more than 20,000 or 30,000 miles, but occasionally they rise far higher than even the largest of the clouds of the preceding class. Their spectrum is very complicated, especially near their base, and often filled with bright lines—those of sodium, magnesium, barium, iron and titanium being especially conspicuous. They usually appear in the immediate neighbourhood of spots never occurring very near the solar poles. Their form and appearance change with great rapidity so that the motion can almost be seen with the eye—an interval of fifteen or twenty minutes being often sufficient to transform, quite beyond recognition, a mass of these flames 50,000 miles high, and sometimes embracing the whole period of their complete development or disappearance. Sometimes they consist of pointed rays diverging in all directions like hedgehog spines. Sometimes they look like flames; sometimes like sheaves of grain; sometimes like whirling water-spouts capped with a great cloud; occasionally they present most exactly the appearance of jets of liquid fire, rising and falling in graceful parabolas; frequently they carry on their edges spirals like the volutes of an Ionic column; and continually they detach filaments which rise to a great elevation gradually expanding and growing fainter as they ascend until the eye loses them.' Sir Robert Ball's description of these prominences ('The Story of the Heavens,' p. 56) is not less full and graphic. Their characters thus described appear to be strongly confirmatory of the theory of a cooling, solidifying process in progress from the solar polar regions towards the equator. The resemblance of the quiescent type to the various forms of terrestrial clouds and due, according to the supposition of Professor Young, to local cooling, taken along with the fact that they are usually situated at the poles, would indicate a lower temperature there, and a closer similarity

to terrestrial conditions. The eruptive form of prominences, on the other hand, situated chiefly in the neighbourhood of sun spots, would indicate that they are due to openings formed in the superficial solidifying layer by the upward movement of the spots, allowing of the escape of molten liquids and gases. Their great force and velocity would show that there must be, according to mechanical principles, some solidity on which pressure could be exerted. The chemical composition of the eruptive prominences as revealed by the spectroscope indicates the presence in the sun of a number of elements met with on the earth. There is here, then, instead of the similarity and analogy of various phenomena, an actual identity between the earth and the sun.

CHAPTER IV

THE CORONA

THE Corona, only observed during a total eclipse of the sun, is one of the most remarkable and conspicuous of the solar phenomena. Professor Young ('The Sun,' p. 137) remarks as follows: 'A total eclipse is unquestionably one of the most impressive of all natural phenomena, and the Corona or aureole of light is its most impressive feature.' Mr. Maunder ('The Heavens and their Story,' p. 150) observes: 'And enveloping both in a wonderful pure, cold radiance stretching out far beyond them is a silver glory: not a halo only but a crown, a glory like nothing else we see on earth or in the heavens. We must compare it to many things. It is like a silver mist, it is like ivory gauze, it is like the wings of an angel, it is like the petals of the lilies of the heaven. Its form takes on here and there the shape of a flower-leaf, and when I saw the sun's eclipse in 1898 it seemed to me as if a child had been playing the game of "Loves me, loves me not," until but three or four of the sun-flower petals had been left on the red-trimmed black-hearted stalk.'

The situation of the Corona in association with the sun spots and the changes it undergoes in its appearance with the waxing and waning of the sun-spot cycle, strengthens the evidence indicating a difference in the state of the photospheric material in different latitudes of the solar surface. Referring to the situation of the Corona, Professor Young remarks: 'On the whole the Corona is usually less extensive and brilliant over the solar poles, and there is a recognisable tendency to accumulations above the middle latitudes or spot zones, so that, speaking roughly, the Corona shows a disposition to assume the form of a quadrilateral or four-rayed star, though in almost every individual case this form is greatly modified by abnormal streamers at some point or other.' The change in the appearance of the Corona in the course of the periodical sun-spot cycles is graphically described



FIG. 9.—TOTAL SOLAR ECLIPSE, JANUARY 22, 1898 (20 sec.). (W. H. M. Christie.)
[By kind permission of the Astronomer Royal, Sir Frank W. Dyson.]

by Mr. Maunder as follows: ('The Heavens and their Story,' p. 158) 'When there are many spots and they are scattered widely over the zones in which they may appear, then the silver petals of the great sun-flower are many and surround the whole of the stalk. The child has not begun to play the game of "Loves me, loves me not," has not plucked out any of the silver petals, but has only ruffled them, broken them, cramping one behind another in a bunch here or spreading them out there. But he plays his game as the spots diminish, and creep downwards to the sun's equator, the petals are ruthlessly pulled out, and if we look upon the eclipsed sun, at such a time we see but the short protecting leaves, and here and there a long petal remaining, looking longer by its solitariness, and when the cycle has reached its time of minimum activity and the sun spots lie only in two narrow zones to the north and to the south of the sun's equator, then the resemblance to the silver sun-flower has departed and the sun's Corona has become like four great wings, angel's wings, folded wings, one pair stretched along to the east of the sun, the other to the west, whilst round the north and south poles of the sun a beautiful row of fine plumes like rays is seen, each plume bending more or less away from the pole. The Corona, like the prominences, the spots and the faculæ, has its cycle of changes which it runs through in about eleven years.'

The equatorial corona is thus seen to differ in several respects from the polar, the greatest contrast being at the times of the sun-spot minima and maxima. Illustrations typical of the former are given in Professor Young's book at pages 243 and 245 from drawings by Grosch and Schott, while at pages 248, 251, and 255 there are illustrations typical of spot-maxima coronas. Markedly fine illustrations of the Corona from photographs taken at different times are produced in the books of Mr. Maunder and Sir Robert Ball.

By Kepler and other astronomers up to the beginning of the nineteenth century it was supposed to belong to the lunar atmosphere. Then it was supposed to be a phenomena of the terrestrial atmosphere. With the aid of the spectroscope and photography it was shown by the American professors Harkness, Young, and Pickering that it was a true solar appendage, and this was confirmed by the observations of Mr. Proctor, who suggested its affinity in constitution to cometary appendages, the Zodiacal Light, and

the Aurora Borealis. In descriptions of it the term 'envelope' has been used, as in the following remarks by Mr. Hector Macpherson, jun., in his book ('The Romance of Astronomy,' p. 58): 'The first solar envelope is the photosphere, that bright, calm-looking solar surface on which the spots appear and from which we derive our light. Above this are envelopes technically known as the Reversing layer and the Chromosphere. Beyond the Chromosphere is the Corona, a soft silvery radiance which can only be seen when the sun is totally eclipsed. The Corona has long proved a problem to astronomers. Its shape varies in sympathy with the eleven-year period, and it seems closely connected with electricity and magnetism. It streams out from the sun for millions of miles, becoming more and more rarefied until it gradually fades into the ether of space. It is the final solar envelope, calm and peaceful, a fitting crown for the "Orb of Day."' It may here be noted that the term 'envelope' has also been applied to the structures surrounding the nucleus of a comet and forming the head, which, according to Sir John Herschel, are continuous with the tail, the continuity in the Corona being between the inner and outer corona. The polarisation of the coronal light and its continuous spectrum indicate the presence of a large amount of reflected light, and this is what is revealed in the tails of comets, the Zodiacal Light and rings of Saturn.

Besides reflected sunlight the presence of gases, of electricity and of the light of incandescence has been shown in the Corona and in comets. Professor Young, quoted by Mr. Macpherson, jun., describes the coronal spectrum as composed of four superposed spectra. First, there is the continuous spectrum, due probably to incandescent dust or solid and liquid particles near the sun. Secondly, the gaseous spectrum, indicating the presence of gases of a permanent nature. This spectrum is distinguished by a green line which has not been identified with any known terrestrial element. Thirdly, there is the continuous spectrum of reflected sunlight with the dark Fraunhofer lines due to sunlight reflected from meteoric dust; and, fourthly, the light reflected from the earth's atmosphere.

In the course of an investigation regarding the nature of comets it was elicited that the Corona is a light-reflecting envelope surrounding the sun, akin in its nature—as derived from gases—to the tails of comets and the rings of Saturn. In the Corona the rings of Saturn are represented by the

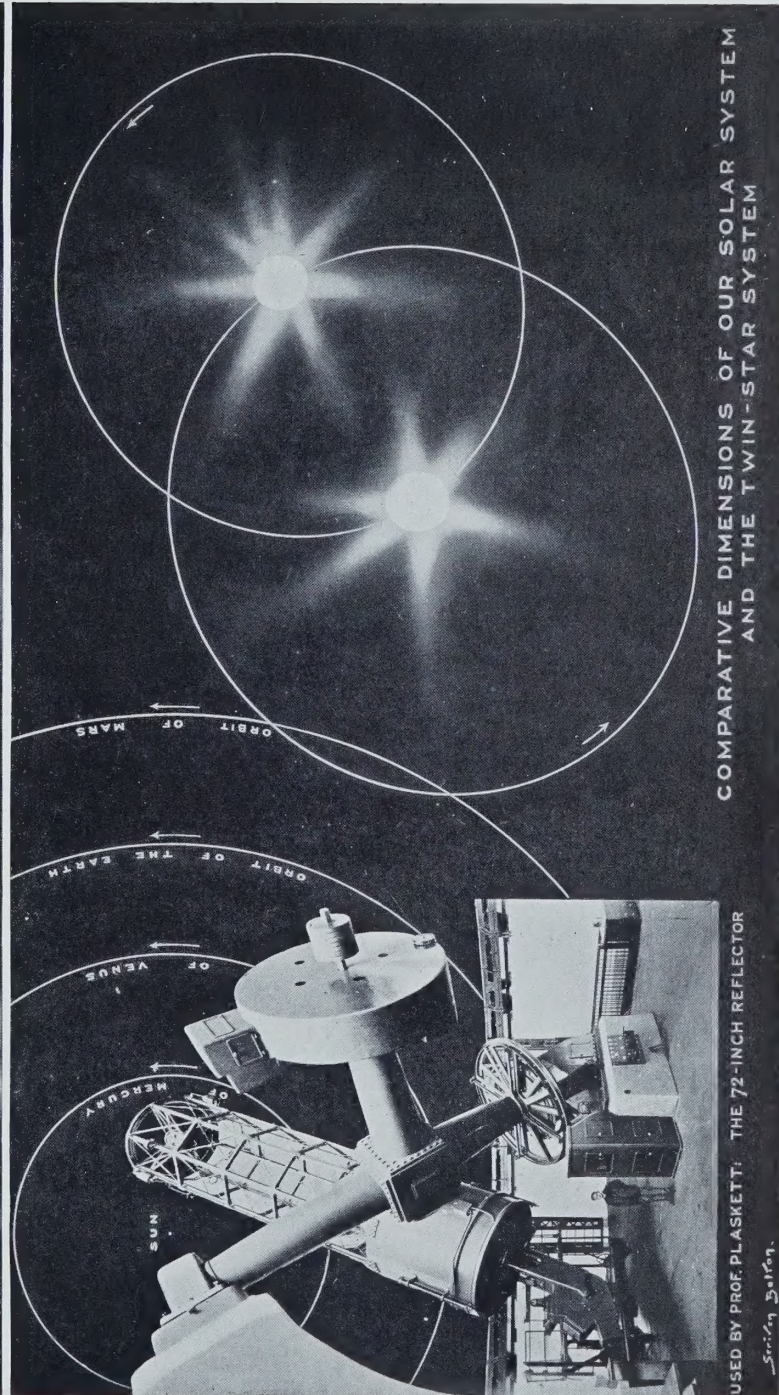
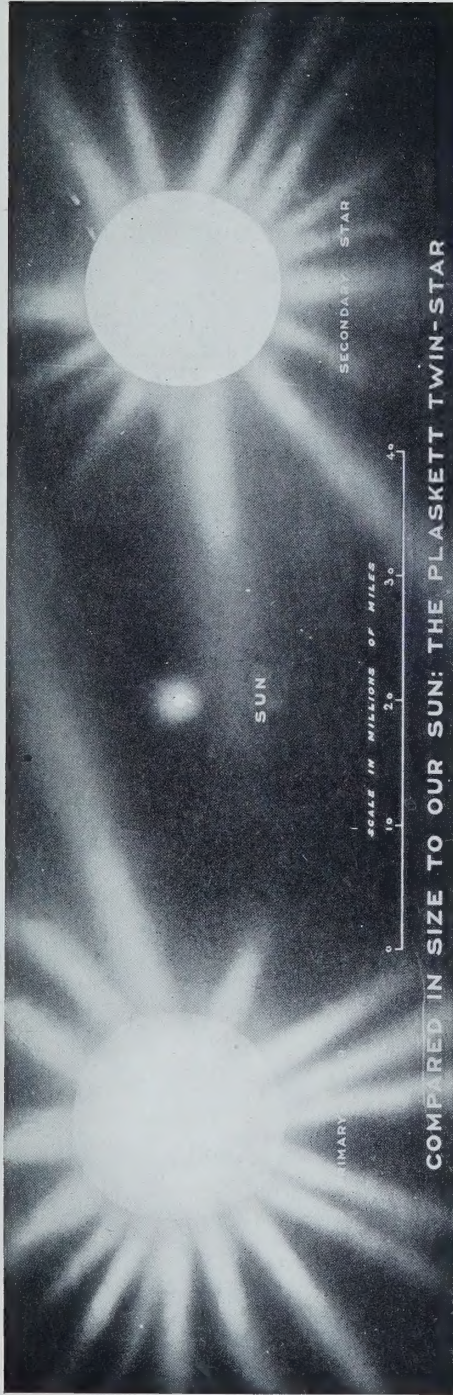


FIG. 10.—There is here represented a comparison in size between our sun and the Plaskett twin stars. As the sun is a star it might be expected that its appendage the Corona will have a counterpart in the other stars, and this seems to be evident in the above-mentioned stars as shown in this drawing.

[By kind permission of the *Illustrated London News*.]

equatorial streamers, and the presence of the currents from outside and from the poles which flatten the rings is shown in the Corona by the fact observed by Mr. Maunder that 'each plume or tuft of the polar Corona bends more or less away from the poles.' In the Corona and the rings of Saturn the heat is central and intrinsic, whereas in comets it is external and eccentric, though it may accumulate locally in sufficient force to produce incandescence and be a generator of gases and electricity.

As the sun is a star it might be expected that its appendages will have a counterpart in the stars, and for comparison with the Corona reference might be made to the Plaskett twin stars and their appendages, as figured in the *Illustrated London News* of April 21, 1923. A periodic alteration similar in appearance to that of the Corona which is coincident with the cycle changes in the sun spots might occur in the appendages of some of the stars. This, if observable, might increase our knowledge of those evolutionary stages which are marked by the colours red, yellow, and white.

CHAPTER V

THE SOLAR ORIGIN OF THE PLANETS

A New Theory

As some of the facts elicited regarding the cooling and solidification of the sun and the nature of sun spots seem to throw fresh light on the important problem of the origin of the planets, it may not be altogether unreasonable to refer to this and to submit a new theory, especially seeing that a number of cogent difficulties appear against an implicit adherence to the nebular theory formulated by Laplace in the year 1796 and generally accepted at the present day. Criticising the Laplacian theory the late Professor Barrell of Yale University wrote Lull ('Evolution of the Earth,' p. 12) as follows : 'Still more fundamental objections, emphasised by Chamberlin and Moulton, are found in certain dynamical relations of the solar system. It would be expected that in condensation the central mass would continually abandon matter from its equatorial zone, the inner planets would presumably have possessed the greater masses, and the final sun would now show a high speed of rotation giving an equatorial diameter far greater than the polar. Such expectations are contrary to the facts. The sun revolves so slowly on its axis, once in twenty-five days, that it has no measurable equatorial bulge. In other words the centrifugal force is negligible in the sun. Furthermore, the equatorial plane of the sun instead of lying precisely in the mean plane of the planet's orbits is inclined seven degrees to such a plane.'

Mr. Abbot, in his book ('The Sun,' p. 412), gives a clear definition of the theory with a notice of some of the imperfections which had been ascribed to it in the following words : 'The famous Laplace, in 1796, crystallised and amplified the conceptions which earlier philosophers had foreshadowed into his famous Nebular Hypothesis of the formation of the solar system. As modified a half-century later by the discovery of the conservation of energy,

it presumes a gaseous nebula larger than Neptune's orbit, in primitive rotation. By virtue of its immense extent it contains potential energy of position which is transformed into heat as the nebula condenses and thus is supplied the energy of radiation. The gravitation of the nebula in conjunction with the occasional collisions of its molecules tended, it is supposed, to produce condensation. At certain critical times the revolving mass separated rings and these by condensation produced the planets. The planets in condensation likewise threw off rings which formed the moons. In Saturn's case, rings still persist. . . .

'According to Chamberlin and Moulton the Laplacian Hypothesis, even as modified and clarified by the work of Helmholtz, Roche, Darwin, and others, fails conspicuously to account for a number of things: (a) The considerable eccentricities of some of the planetary orbits and the inclinations of their planes among themselves, and with respect to the sun's equator; (b) the negative rotation of some of the satellites, and the small periods of revolution of some of them as compared with the periods of rotation of their primaries; (c) the difficulty of understanding how rings could be left off in the shrinking of the nebula, whether it were gaseous or meteoric in structure, and the still greater difficulty of understanding how a ring, if left off, could condense into a planet; (d) the difficulty of accounting for the enormous discrepancy between the present moment of momentum of the system and that which must apparently have formerly prevailed.

'Chamberlin and Moulton have proposed the "Planetesimal Hypothesis" of the evolution of the solar system. They might start with a spiral nebula. Since there are millions of these objects in the sky this basis is justified.' . . . 'Professor T. J. J. See has just published (after the above *résumé* of nebular hypotheses was written) his volume on the subject. In his view the sufficiently close approach of two stars to form a spiral nebula, as assumed by Chamberlin and Moulton, is too infrequent to deserve consideration. . . . Such a spiral nebula is, according to him, the parent of the solar system, but, unlike Chamberlin and Moulton, his nebula would not have its central condensation, the sun, mainly formed before the planets began to form, but all would be forming at the same time, by capture of particles by larger masses in the exercise of mutual gravitation, and in the vicissitudes of mutual encounter between the larger and smaller bodies of the nebula.'

Sir Robert Ball, at p. 4 of his book, 'The Earth's Beginning,' refers to three of the greatest names in science, Kant, Laplace, and William Herschel, as founders of the nebular theory of the origin of the stars and the solar system, and he adds the following remarks: 'Laplace was careful to say that the nebular theory which he sketched must necessarily be judged by a standard different from that which we apply to astronomical truths revealed by telescopic observation or ascertained by actual calculation. The nebular theory, said the great French mathematician, has to be received with caution, inasmuch as, from the nature of the case, it cannot be verified by observation, nor does it admit of proof possessing mathematical certainty.'

In the course of his lectures largely 'devoted to the evidence bearing on this famous doctrine' (p. 116 of this book) Sir Robert Ball gave expression to the following observations: 'We must not pause to consider intermediate stages. We shall look back at once to an excessively early period when the sun—or perhaps we ought rather to say the matter which in a more condensed form now constitutes the sun—was expanded throughout the volume of a globe whose radius was as great as the present distance from the sun to the earth. Have we not here truly an astonishing result deduced as a necessary consequence from the fundamental laws of heat? I need hardly say that the sun at that early date did not at all resemble the glorious orb to which we owe our very existence. The primeval sun must have been a totally different object, as we can easily imagine if we try to think that the sun's materials then filled a volume twelve million times as great as they occupy at present. Instead of comparing such an object with the gases in our ordinary atmosphere, it should rather be likened to the residue left in an exhausted receiver after the resources of chemistry have been taxed to make as near an approach as possible to a perfect vacuum.' To these observations the following inquiry seems not inapplicable. If this was the condition of the sun when it extended to the orbit of the earth with a radius of 93,000,000 miles—*viz.* a near approach to a vacuum—what would be its condition when it extended to the orbit of Jupiter with a radius of 483,000,000 miles, and how could it throw off a ring to form this planet, not to mention the throwing off of rings to form the three more distant planets? Some other defects in the nebular theory may be worth noting: (1) There is no satisfactory account of the causes which might produce the critical times for the throwing

off of rings ; (2) the outer planets, according to the theory being the oldest, ought to be the coldest and densest, having had a longer time to cool and being farther away from the heat of the sun, whereas the reverse is the fact ; (3) there is no explanation of the fairly regular gradation of the densities and distances of the planets ; that of the former would, as stated, be reversed.

Owing to certain defects in the Planetesimal Hypothesis of Chamberlin and Moulton, and its modification by Professor See, Mr. Herbert Spencer Jones has brought under notice the theory formulated by Jeans. It may, however, be remarked that there remains the difficulty of the infrequency of the possibility of the encounter of two bodies, the sun being one of them. Secondly, there seems to be a want of proof for the conclusion that at birth there was a difference between the smaller and the larger planets, the former being 'liquid or solid' and the latter 'gaseous.'

An inducement to direct attention to the sun spots as the source from which the planets have been derived is afforded by the theories which have been framed regarding the separation of the moon from the earth, and to this may be added the following remarks by Sir Robert Ball : 'Make now a bold stretch of the imagination. Conceive a mighty cannon capable of receiving a round bullet not less than 2000 miles in diameter. Discharge this enormous bullet with a velocity of about 3000 feet per second, which is two or three times as great as the velocity actually attained in modern artillery. Let this notable bullet be fired horizontally from some station nearly a quarter of a million miles above the surface of the earth. That fearful missile would sweep right round the earth in a nearly circular orbit and return to where it started from in about four weeks. Do not suppose that we are entirely romancing. We cannot indeed show the cannon, but we can point to a great projectile. We see it every month—it is the beautiful moon herself. No one asserts that the moon was ever shot from such a cannon ; but it must be admitted that she moves as if she had been.'

According to the theory here submitted, the central point of which is that a process of cooling and solidification has been going on in the sun extending from the poles towards the equator, and from the surface towards the interior, and that in the course of time the sun came to present the form of a huge cavity or cavities occupied by gases under inconceivably great pressure especially near the centre, having some solid resisting material in

the higher latitudes, with surface-cooled material extending further towards the equator and forming a shell. Owing to the difference in temperature and density between the solidifying material at the poles and the molten fluid and gases at the equator, and the increased pressure, currents would develop and detached portions of more or less solidified substance of various sizes would be conveyed towards the equator. As these might be driven by explosive forces from below, they would impinge on the inner surface of the surface solidifying material, and raising and penetrating through it would appear as sun spots. Some of these might be welded together, moulded and rounded into a single mass of great size. Under favourable circumstances this mass, surrounded by vast oceans of explosive material, might be discharged with great force and form a planet, and successive discharges might take place in correspondence with the sun-spot cycles. This view of the origin of the planets is further supported by the fact that the distances between the planets is so regular that a law of progression was framed, and this was adopted by such eminent astronomers as Kepler, Titius, Bode, Wollaston, Piazzzi, Baron de Zach, and others. The following table given in the article on Astronomy in the 'Encyclopædia Britannica' illustrates this law.

Mercury	Venus	Earth	Mars	Missing Planet	Jupiter	Saturn	Uranus
4	4	4	4	4	4	4	4
0	3	6	12	24	48	96	192
4	7	10	16	28	52	100	196
3·9	7·2	10	15	—	52	95	192

The writer of the article explains the table as follows: 'Here the series 7, 10, 16, etc., is obtained by adding to 4 successively the numbers 3, 6, 12, 24, etc., forming a geometrical series, and the distances of Venus, the earth, Mars, Jupiter, etc., which are indicated in the lowest row, are found to correspond with the members very closely indeed.' By carrying out observations

in accordance with this law the planets Ceres and Pallas and subsequently the other members of the asteroid group were discovered. It thus appears that the regularity in the intervals between the planets is very noticeable. There is some approach to regularity in the recurrence of sun-spot cycles. Another point to be noticed is the gradation of the densities of the planets from within outwards, whereas if the nebular theory were true the outer planets would be the densest and the gradation reversed.

The following table represents the densities of the planets, as supplied by the author of the article Astronomy in the 'Encyclopædia Britannica.'

Name	Density	Name	Density
Earth as	1	Asteroids	—
Mercury	1·12	Jupiter	0·24
Venus	1·03	Saturn	0·13
Earth	1	Uranus	0·17
Mars	0·70	Neptune	0·16

Tracing the process of solidification in the sun it may be inferred that there will be a large number of openings in the material solidifying from the surface, increasing in size from the poles towards the equator, through which fluids and gases may escape and form the bright areas of the photosphere, or if these issued under great force they might produce the eruptive prominences. Sun spots appearing from beneath may raise the surface material into hillocks or faculæ or form the penumbra of the spot, the central dark portion being the body of the spot. Under certain conditions the solidifying material may be so moulded round the sun spot as to form a vast mechanism suited for its discharge to the position where it is known as a planet. In the earlier period of the sun's history, when there was a comparatively small amount of solidified material forming a mechanical medium of resistance, the planets would be comparatively small and the

distance to which they would be propelled would also be smaller than at a later period.

The phenomenon of the asteroids differing in size and number from the planets may find a not unreasonable explanation in the supposition that in the course of moulding there was an aggregation of comparatively loosely adherent smaller bodies instead of one large one, and that, as the result of the force of the discharge, these would separate and form into the small planets. The evacuation of these might produce a clearance in the sun with an enlarged exit permitting of the moulding and discharge of the outer and later planets which are much larger in size than the inner and earlier planets which obtained their size before the evacuation of the asteroids.

The question of the origin of the sun itself, which is a star, forms a part of stellar astronomy, and it is satisfactory to note that so eminent an astronomer as Professor G. Ellery Hale, equipped with the finest observatory instruments, including the great Carnegie telescope, has been devoting his attention to this department of astronomical research.

His conclusion, as given in a short extract from an article by him, published in *Scribner's Magazine* on the 'Heat of the Stars,' is that a star—taking Betelgeuse as an example—passes from a gaseous mass through the red and yellow stages to the white, and then back from the white through the yellow to the red. The first of these courses would seem authoritatively to confirm the nebular theory of the origin of a star. At the same time it does not necessarily invalidate the theory here respectfully submitted of the solar origin of the planets, as these may have been formed during the receding course of the sun from the white passing through the yellow, its present stage, to the red.

APPENDIX I

THE TAIL DEMANDED BY GRAVITATION

AT p. 161 of Sir Norman Lockyer's book, 'The Meteoritic Hypothesis,' there is the statement of M. Faye quoted with approval by Sir Norman Lockyer. 'There exists, for every body placed within the sphere of action of our sun, a surface limit, beyond which its matter may not pass, under pain of escaping from that body and falling within the domain of the solar action. . . . But for a comet this surface limit is much nearer the nucleus, and, moreover, it draws nearer and nearer in proportion as the comet approaches the sun.' That is, that in a comet, although 'falling freely to the sun,' the surface limit does not disappear, but only has its position changed and matter may still pass beyond it towards the sun. This is the tail which, according to Sir Norman Lockyer's reasoning from a Memoir by M. Roche, is demanded by gravitation, as stated at p. 163. According to the theory noticed by Mr. Herbert Jones, Royal Astronomer at the Cape, only particles of a certain size in a comet come under the radiation pressure of light instead of the attraction of the sun. Mr. Maunder in his theory seems to give all particles under $1/25000$ th part of an inch as suitable for the pressure of light. MM. Roche and Faye formulated a theory to suit particles of various sizes. Some of these would pass beyond the surface limit of the comet towards the sun and form 'the tail demanded by gravitation' of Sir Norman Lockyer, were they not driven back by the pressure of light. According to the theory, I venture to submit it seems contrary to terrestrial experience that the radiation pressure of light should be able to eliminate the gravitation tail mentioned by Sir Norman Lockyer; should at the same time suddenly and uniformly curtail the radiation pressure of local light derived from incandescence, luminous gases and electricity; should at the same time, and with the same suddenness and uniformity, overcome the dispersive action of heat, electricity, and the rapid forward movement of a comet, and finally drive certain material for many millions of miles in

a fairly straight line. A transparent envelope will have an ideal light-reflecting surface, will retain dust, and will permit of the observation of the contained material. It will give direction to gases, and the forces of light, heat and electricity. It will explain such phenomena as the diminution in size of the head on its approach to perihelion, multiple tails as in the comet of 1744, and the presence of tails in the east after Halley's comet had gone to the west. It might be torn up to resemble locks of hair, hence the name comet.

THE CURRENTS FROM THE COLD OF SPACE PRESSING ON THE HEAD OF THE COMET

The observations and researches of Chladni, Adams, Schiaparelli, and many others seem to have shown conclusively that the opinion long held that space is a vacuum is now untenable.

Sir Norman Lockyer, at page 111 of his book 'The Meteoritic Hypothesis,' writes as follows: 'It is not so many years ago since planetary space was supposed to be untenanted by anything more tangible than that mysterious fluid called ether. This notion is exactly represented by the French equivalent for that space, *le vide planétaire*.' At p. 133 he remarks: 'The *vide planétaire* is now ultimately abolished, and we find the solar system to be a meteoritic *plenum* in which sporadic meteorites and swarms of greater or less density are moving in orbits more or less elongated round the sun.' At p. 145 he states: 'In 1873 the following views were expressed in the Report of the B. A. Committee on Luminous Meteors:—

'The extraordinary meteorological changes which comets undergo from the eccentricities of their orbits may, by the process of a kind of "weathering," disintegrate their surfaces sufficiently to scatter such bodies in crowds along their paths. In this view, instead of presupposing the existence of cosmical clouds containing all these several bodies separately formed, comets may be regarded as parent bodies from which aerolites and shower-meteors are similarly derived.'

In accordance with the well-established fact of the affinity between comets and meteors and the spectroscopic revelations of gases associated with the former, it seems reasonable to suppose that gases will be associated with meteoric material, and that these will be subject to condensation and expansion by cold and heat. On the earth gases pass from a region where there is cold and condensation to take the place of gases expanded and rarefied by heat. Hence there is a general movement of the atmosphere

from the poles towards the equator, and local developments take the names of breezes, winds, gales, hurricanes and others, all of which come under the general term of currents. In a typical comet, owing to the eccentricity of its orbit, the difference between the extremes of heat and cold will be very much greater than on the earth. In the comets of 1680 and 1843, both of which had long tails, the heat which would be concentrated on the side of the comet next to the sun must have been so great, as calculated by Sir John Herschel and Sir Robert Ball, that any material on the earth, however hard, would be made to 'run like water.' On the sheltered side of the nucleus there would be the extreme of cold by which gases from the opposite side would be cooled and condensed. These would pass round the nucleus in the form of currents of great force to the locality where there was the greatest expansion and rarefaction by heat. On account of their great force they might carry with them dust and perhaps larger particles, some of which might be attracted by the sun, but the greater portion would undergo dispersion by the radiation of light derived from local sources and by the dispersive action of heat, electricity, and the rapid forward movement of the comet. Instead of that, they are suddenly and uniformly driven back with a sharp demarcation between the comet and space, indicating some boundary material the continuity of which, from the coma to the tail, shows the identity of their structure. Through the boundary material or envelope rarefied gases might pass by a process of osmosis to outer space. It is a recognised fact that there is a cold in space, which would cool and condense these gases, and some of them would then return in the form of currents to take the place of the heated and rarefied gases in the comet and in doing so would exert pressure on the envelope from the outside. It seems not unreasonable to suppose that comets might at intervals pass through gases derived from meteors which have been cooled by space and even through swarms of meteors themselves. Thus it may be that the reason why Halley's comet has not been disintegrated long ago—about which there have been many speculations—is that the comet, in the course of its seventy-six years' orbit, collects sufficient meteoric material to last its perihelion passage so that a balance is kept up both within and without the envelope.

THE NUCLEUS AND TAIL OF A COMET

'No comet without a nucleus has a tail.' It has been supposed by some authorities that Ensor's comet of 1926 was an example refuting this statement in the text. With reference to this the following note has been

kindly sent to me from the Union Observatory, Johannesburg. 'During this period (December 14, 1925, to January 22, 1926), the period of observation of Ensor's comet, the comet developed a very short tail, which was about $\frac{1}{2}$ degree in length on January 20, coma was large and round with a sharp stellar nucleus.'

Mr. Ensor kindly supplies me with the following information regarding the subsequent history of the comet: The comet should have been seen in the eastern sky during the last days of February. Although constantly searched for along its predicted route by all the principal observatories of the Northern Hemisphere no trace of it could be discovered. The comet had completely vanished. Professor Frost of the Yerkes Observatory, who had been searching with the famous 40-inch telescope, was of the opinion that the sun had so expanded the comet that it had become practically invisible. 'A celestial jelly fish,' as an American paper described it, when it should have appeared 'with a full tail and a red face' according to the same paper. At last on March 10 Mr. B. M. Peak, a well-known British amateur, refound the comet. It had expanded to such an extent that it quite filled the field of the telescope, and appeared as a faint nebulous mass. Mr. Peak also managed to secure a photograph.

On March 16 and 20 the comet was photographed by Dr. Schoor of the Bergedorf Observatory, Germany. A reproduction of the photographs, kindly sent to me by the Director of the Observatory, shows the comet as a very faint nebulosity without any trace of a nucleus.

The comet was also observed in Leningrad, Russia, by members of the Russian Astronomical Society Mirovedenie. These observers ascended above the clouds in a captive balloon, and by means of powerful binoculars saw the comet as a dim, indistinct spot 8 ft. to 10 ft. in diameter, its general brightness being about magnitude 5. A faint tail was seen. It will be noted from these observations that in the earlier part of its course the comet had a distinct stellar nucleus and that this was associated with a tail. During the perihelion passage the nucleus may have been dispersed by heat, the dispersed material consisting probably of gases interspersed with dust might increase the nebulosity of the coma and assist in maintaining a faint tail. Thus the appearance presented by the comet in March would scarcely warrant the conclusion that this was an example of a comet refuting the statement that 'no comet without a nucleus has a tail,' especially as some considerable alteration seems to have occurred in the comet when passing the sun, as evidenced by the difficulty of finding it and the term 'celestial jelly fish' which was applied to it.

A DISINTEGRATING SATELLITE

The particles and fragments of a disintegrating satellite would be scattered in all directions, and the difficulty would be to arrange them round the equatorial circumference. According to my theory, they originate from the equatorial circumference, and this difficulty is avoided.

THE DENSITY OF THE SUN

The densities of the sun's constituents were treated according to terrestrial standards of the sun's constituents, and, judged by these, it would appear that the sun has a density greater than water. Mr. Abbot, a very eminent authority on the sun, formulated a theory giving it a wholly gaseous constitution, but certain facts seem to indicate that it is undergoing a process of cooling and solidification.

THE CORONA AND THE APPENDAGES OF THE STARS

As the sun is a star it might be expected that its appendages will have a counterpart in the stars, and for comparison with the corona reference might be made to the appendages of the Plaskett twin stars, a figure of which appears in the *Illustrated London News* of April 21, 1923.

THE DENSITIES OF MERCURY AND VENUS

Recent estimates seem to give the densities of Mercury and Venus as lower than that of the earth. This may be owing to the circumstance of their proximity to the heat of the sun. There remains the fact of the densities of the earth, Mars and Jupiter being greater than that of the outermost planets.

THE PLANETARY ORBITS

Some authorities are under the impression that a body ejected from the sun would in its orbit return to its source. As proof, the example is given of a fast moving train, in which were a passenger to throw up a ball it would return to his hands. Here it will be noted that the force with which the ball is thrown is very much less than that of the train. In like manner

many bodies thrown out of the sun with less force than its forward movement will return to it, but in the case of even the planet nearest the sun the ejecting force is so great that it attains a distance far beyond the range of the forward motion of the sun, and the force which it to a large extent obeys is the sun's attraction. This, although not sufficiently powerful to draw the planetary body directly back to the primary, keeps it under control until the orbit, which is at first a curve, becomes a circle.

APPENDIX II

Extract from Circular of Cape Union Observatory. With the kind permission of R. T. A. INNES, Esq., Union Astronomer.

TRANSVAAL OBSERVATORY. *Circular No. 4, July 11, 1910.*

At the request of the Director I have secured photographs of Halley's comet at every possible opportunity. These have been taken with the 10-inch Cooke lens, 44·6 inches focus, of the photographic equatorial presented to the Transvaal Government by Mr. J. Franklin-Adams, of London. This instrument is described in the Monthly Notices of the Royal Astronomical Society, Vol. 64, p. 608. It is provided with two guiding telescopes, one of which has an independent swivelling motion in two directions. This was found most useful when the length of the comet's tail exceeded 8° . The dates of the exposures will show that very few opportunities of photographing the comet were lost during the period 11th April to 3rd June. The weather conditions were very favourable throughout this period, the only trouble being the presence of the moon in the sky on many days. Of the photographs obtained the majority show a composite tail consisting of a number of rays proceeding apparently from a point just behind the nucleus. The envelopes surrounding the nucleus appear to form a cap over the tail.

May 9.—Plate IV, No. 21.—Exposure from 14 h. 17 m. to 14 h. 48 m. Tail $1^{\circ} 9'$ wide at 5° from nucleus. Inclination to meridian 256° . Tail mainly straight, with a bright streamer leaving the south edge at about $1^{\circ} 30'$ from the nucleus. The tail contains a large number of rays, the two brightest being near the north edge. The nucleus of the comet is now very bright, and the envelopes appear to continue and form a sheath or cap over the tail.

May 9.—Plate IV, No. 22.—Exposure from 14 h. 53 m. to 15 h. 24 m. Tail 1° wide at 5° from nucleus. Inclination to meridian 257° . Details similar to No. 21. Between the streamer leaving south edge of tail and the main tail appear two fainter streamers. Long bright sheath.

May 10.—Plate IV, No. 23.—Exposure from 14 h. 19 m. to 14 h. 49 m. Inclination of tail to meridian 257° . The tail appears slightly convex towards south. The edges of the envelopes are sharper on the north side than on the south, otherwise the emission appears symmetrical. The tail is not so bright along the centre line.

May 11.—Plate IV, No. 24.—Exposure from 14 h. 33 m. to 15 h. 06 m. Inclination of tail to meridian 257° . The centre of the tail is dark, with a bright ray running along the north side of the dark space. This ray curves towards the south at 4° from the head.

April 16.—G.T. 3 h. Plate X, No. 1.—A secondary nucleus measured at $48^\circ.3, 12''.0$.

April 18.—(a) Plate X, No. 2.—Nucleus elongated 3×2 in $113^\circ, 3''.4$ by $2''.0$ by very rough measures. There is a secondary nucleus at $154^\circ \pm, 5'' \pm$. The tail is 4° long, and at $\frac{3}{4}^\circ$ from head is $16'$ in diameter. There is an extension of nebulosity towards the sun. The south side of the tail is the brighter.

(b) S. branch of tail brighter than N. branch. Nucleus elongated 147° to 327° . [W.M.W.]

April 19.—(a) Plate X, No. 3.—Is 3rd mag. and still visible in dawn; no secondary nucleus seen.

(b) Nucleus less well defined on *f.* side. S. tail brighter and longer than N., but the brightest part of the whole tail is the S. edge of N. tail near head.

April 21.—(a) Plate X, No. 4.—Secondary nucleus seen, but indistinctly. The two nuclei were involved in the haze of the coma. A dark vacancy immediately behind the main nucleus.

(b) Secondary nucleus or slight condensation at $123^\circ \pm$.

April 22.—(a) Plate X, No. 5.—Comet's head decidedly one-sided; all the off-streaming is on the S. side. The secondary nucleus seen, but close in to the primary (160°), the two nuclei looking like a big ill-defined double-star.

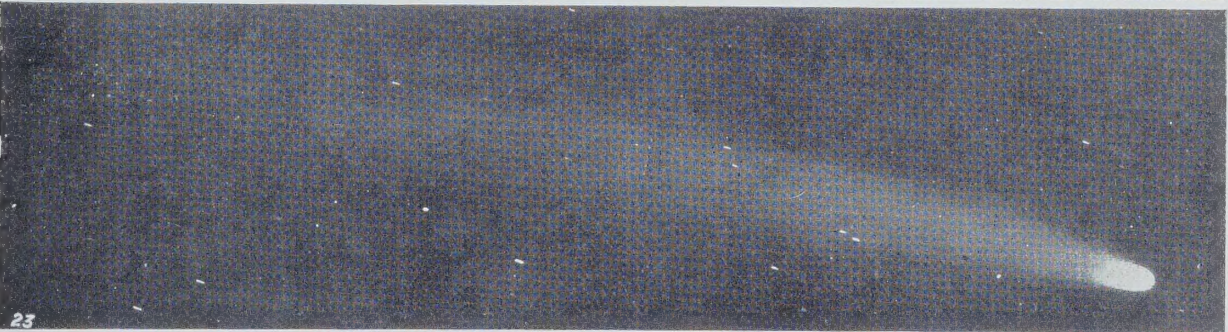
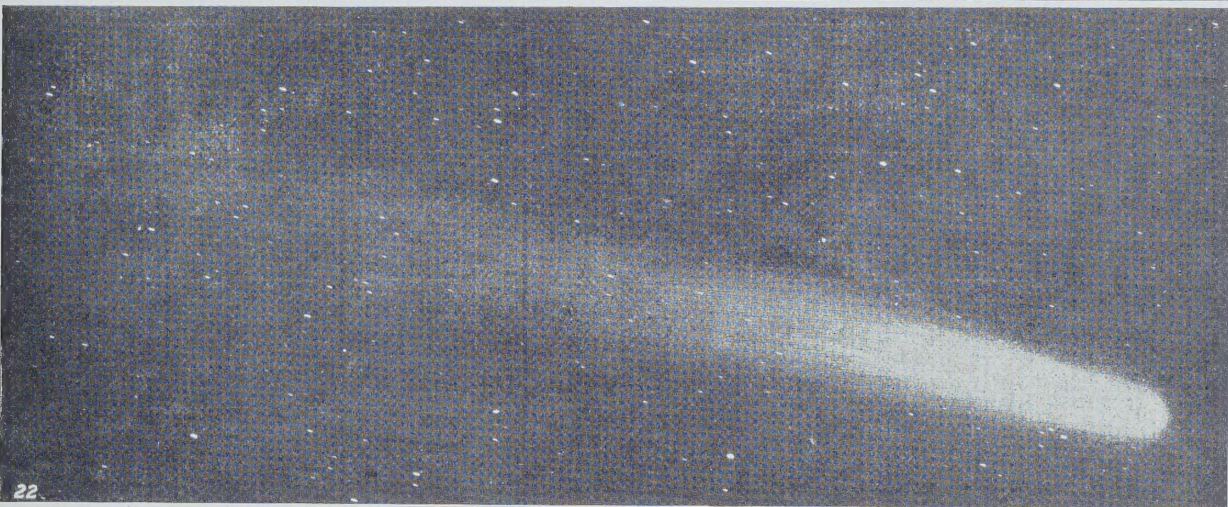
(b) S. side of nucleus ill defined and melting into tail. S. tail brighter than N. branch.

April 23.—(a) Plate X, No. 6.—Nucleus much smaller, the outpouring is all on the S. side; no secondary nucleus seen.

(b) Nucleus fairly well defined, streamers on S. *f.* side. S. tail much the brighter.

April 24.—(a) Plate X, No. 7.—The secondary nucleus is N. *f.* ($80^\circ, 7''$). Both nuclei sharper than previously.

(b) Nucleus fairly well defined generally, somewhat elongated and less



HALLEY'S COMET.

Plate IV, No. 21, May 9, 31 m. exp. No. 22, May 9, 31 m. exp. No. 23, May 10, 30 m. exp. No. 24, May 11th, 33 m. exp.

Transvaal Observatory, No. 4 Circular, July 11, 1910.

well defined in 160° – $340^{\circ} \pm$. S. tail so much more developed than N. branch that the nucleus appears to be very unsymmetrically placed.

April 25.—(a) Plate X, No. 8.—The comet was much brighter this morning. No secondary nucleus seen.

(b) Comet much brighter. Nucleus larger and fairly well defined. Tail more evenly developed, but S. tail is still the brighter and longer.

April 27.—(a) Plate X, No. 9.—Nucleus smaller and more stellar. Butterfly appearance. Star 9.3 mag. close to head and well seen through tail. No secondary nucleus. N. and S. branches of tail more even in brightness.

(b) Nucleus round, brighter, with many streamers. Tail more even, but S. tail still noticeably brighter and longer.

April 28.—Plate X, No. 10.—Nucleus not quite round. Butterfly appearance. S. branch of tail somewhat brighter than N.

April 29.—(a) Plate X, No. 11.—Nucleus more symmetrical. S. branch of tail somewhat brighter than N. branch.

(b) Nucleus small and well defined. Slightly elongated about 160° – 340° with ‘fans’ of streamers at each end. S. tail slightly brighter than N.

April 30.—Plate X, No. 12.—An ill-defined secondary nucleus or bright extension in 120° .

May 1.—(a) Plate X, No. 13.—S. branch of tail is the brighter. A rift has appeared S. of the nucleus.

(b) Nucleus rather smaller and well defined; secondary nucleus suspected at about 30° . N. side of head brighter than S., but S. tail brighter than N. On going to the 9-inch, it was seen that the nucleus was elongated slightly in direction of 150° – 330° , suspected secondary nucleus is apparently specially strong outpouring of matter. Lane in S. branch of tail, bordered on N. by a streamer.

May 2.—Plate X, No. 14.—Nucleus small and stellar, but somewhat indistinct *f*. No jets, etc., clearly seen. S. branch the brighter.

May 3.—(b) Plate X, No. 15.—Nucleus small, bright, rather ill defined. Dark space behind head sharply defined on *f*. side by fan-shaped streamers. S. tail brighter and broader than N. tail. (9-inch.) [N.B.—R. I. was absent attending a congress; Mr. R. J. Mitchell was good enough to come up and make a drawing, Plate X, No. 16. Mr. Mitchell adds: ‘Noticeable features (i) fan-shaped dark space behind the nucleus; (ii) slightly accentuated stream of superior brightness along S. branch of tail; (iii) fan inclined to be brighter on S. side.’]

May 4.—(a) Plate X, No. 17.—S. branch of tail much the brighter.

(b) Plate X, No. 18.—All outpouring seems to be swept round to S. tail,

even that from N. *f.* part of head. S. tail larger and brighter than N. No secondary nucleus.

May 5.—(a) Plate X, No. 19.—Nucleus much smaller, somewhat butterfly appearance. S. and N. branches of tail more even in luminosity.

(b) Plate X, No. 20.—Nucleus small and round. Fan-shaped rays faintly seen. Brightest part of tail is the inner portion of S. branch, otherwise N. branch longer and generally brighter.

May 6.—(a) Plate X, No. 21.—Head decidedly yellowish, an appearance not noticed before. A star was involved in the tail and another was free; the mags. were estimated as 9.0 and 8.0 respectively, a difference of one magnitude. These were identified as B. D. + 8°, 5 and B. D. + 9°, 5 mags. 8.9 and 8.7 respectively, a difference of only 0.2. Hence the tail dimmed B. D. + 8°, 5 to the extent of 0.8 mag., equal to one-half of its light.

May 8.—(a) Plate X, No. 23.—Taken altogether, the S. branch is the brighter. Curious gap between the two main jets. S. edge of the brighter jet was along 85°; it was slightly curved. Nucleus small and stellar.

(b) Plate X, No. 24.—No secondary nucleus. Very prominent gap in fan of streamers.

May 9.—(a) Plate X, No. 25.—Nucleus somewhat larger. N. branch of tail near head is the brighter.

(b) Plate XI, No. 26.—No secondary nucleus. N. branch of tail brighter near head. S. *f.* boundary of head ill defined. Traces of an inner sheath in N. branch.

May 10.—(a) Plate XI, No. 27.—Nucleus larger.

(b) Plate XI, No. 28.—Nucleus slightly elliptical, larger and less well defined. S. branch of tail brighter and broader for more than a degree from head, slight nebulosity outside principal sheath.

May 11.—(a) Plate XI, No. 29.—From this date until the day of transit, the comet with its enormous bright tail was an imposing and beautiful spectacle, far transcending the comets of 1881 or the Great Southern Comet of 1901.

(b) Plate XI, No. 30.—Nucleus elongated, streamers not very prominent. Principal sheath more sharply defined on N. side; on S. side it melts into the outer glow.

May 12.—(a) Plate XI, No. 31.—Nucleus and bright coma decidedly yellow = 3. Extraordinary appearance. Jets are of Prince of Wales's feathers type. Kink on S. side of dark space behind nucleus.

(b) Plate XI, No. 32.—Nucleus small, round, and brighter. Nucleus and streamers yellow = 3. Extraordinary ray from nucleus bent near end towards N. *f.* and terminated in a knob. Inner sheath well defined on N. side, but melting into outer sheath at head and on S. side. S. tail brighter.

May 13.—(a) Plate XI, No. 33.—Nucleus small and quite stellar. S. side of tail brighter near head. Nucleus like a 4th mag. star and yellow. (14 h. 45 m. G.T.)

Nucleus is throwing out an extension in $230^{\circ} 1''$, giving it a double-star appearance (15 h. 5 m. G.T.). Secondary is now at $240^{\circ} 1\frac{1}{2}''$ (15 h. 23 m. G.T.). Triple appearance. Nucleus certainly grown in size since 14 h. 45 m. G.T. (15 h. 32 m. G.T. dawn).

(b) Plate XI, No. 34.—Nucleus small, round, and well defined, yellow = 3. Curious gap in coma N. f. nucleus. S. tail is the brighter.

N.B.—Venus on N. side of zodiacal light. [R.I.]

May 14.—(a) Plate XI, No. 35.—Head yellow, nucleus larger.

(b) Plate XI, No. 36.

May 15.—(a) Plate XI, No. 37.—Unusual appearance. Most glow *behind* nucleus. (15 h. G.T.)

Nucleus changed, well-marked rifts. (15 h. 43 m. G.T.)

(b) Plate XI, No. 38.—Nucleus larger, elongated *p.* and *f.*, yellow = 3. Streamers almost all behind a N. and S. line through centre of nucleus. (15 h. 10 m. G.T.)

N.B.—The comparison-star used this morning was in the coma and was estimated as 9.5, B. D. gives 8.8. It is quite obvious that a star behind the brilliant coma must appear dimmed. The statements on this point in some popular books are inexact.

May 16.—Plate XI, No. 39.—Nucleus large and yellow.

May 17.—Nucleus rose at 5 h. 45 m. Standard Time (dawn). It looked like a mere ball of light $30''$ in diameter, flashing yellow and red. At 6 h. daylight, the nucleus was large, but it was so near the horizon that no detail could be seen. On this and previous days the comet was invisible in a 3-inch at meridian-transit.

May 18.—Day of passage through node and transit across the Sun.

At sunrise the solar disk was carefully scrutinised by both observers with telescopes varying from $\frac{1}{2}$ -inch to 9-inch aperture. Some suspicious objects were seen, especially one near the lower edge of the sun, but continued scrutiny proved that all were sun spots.

EVENING OBSERVATIONS.

May 19.—Fair sky, nothing seen.

May 20.—(a) Plate XI, No. 40.—Comet first seen at 5 h. 40 m., or 13 mins. after sunset. S. branch of tail is much the brighter. Bushy tail, nucleus $6''$ diameter. Great sheath envelopes head.

(b) Plate XI, No. 41.—The comet was picked up at about sunset, but no observations could be made until the sky had darkened considerably. The nucleus was yellow 3, shading off to yellow 4 in the streamers.

May 21.—(a) Plate XI, No. 42.—Nucleus very small. N. part of head much the brighter, otherwise S. branch of tail is the broader and brighter.

(b) Plate XI, No. 43.—Nucleus round and well defined, yellow = 3. Narrow dark gap in the front of the head. N. tail brighter and better defined, S. tail broader. No trace of a tail preceding the head.

May 22.—(a) Plate XI, No. 44.—Strong Moon. Nucleus and head show but little detail to-night.

(b) Plate XI, No. 45.—Very little detail in head. Nucleus yellow = 1.

May 23.—(a) Plate XI, No. 46.—Nucleus eccentric.

(b) Plate XI, No. 47.—Nucleus small, elongated 150° – 330° , yellow = 2. Greatest glow on S. *p.* side of head. N. tail brighter.

May 24.—Plate XI, No. 48.

May 27.—Plate XI, No. 49.—Nucleus very small and quite stellar = $1\frac{1}{2}''$ at 5 h. 55 m. G.T.

May 28.—Tail ends midway between Jupiter and Spica. Nucleus very small and stellar.

May 29.—The tail after the first 30° from the head extends as a very faint and diffused beam of light, somewhat curved towards Jupiter and N. of Spica. Stellar nucleus without jets, but there is a broad brush of nebulosity about $10'$ long springing from the head and pointing sunwards. Tail formation near head much brighter on S. side. (5 h. G.T.)

May 30.—Nucleus small and stellar, no well-defined features or jets. The tail is lost at Spica; it passes betwixt Jupiter and Spica.

May 31.—(a) Plate XI, No. 50*a*.—Nucleus stellar and yellow; unusual jets or rays. A second slight condensation behind nucleus.

(b) Plate XI, No. 50*b*.—(6 h. 5 m. G.T.)

June 1.—All outstreaming from nucleus seems to be in the N. *p.* quadrant.

June 2.—Nucleus is broken up. The chief nucleus is probably the preceding one, which is slightly the brightest. It is followed in 120° , $20'' \pm$ by a double nucleus, also double along 120° , $5'' \pm$, and a band of light joins all three nuclei. (5 h. G.T.)

Angle $111^{\circ} 5'$ at 6 h. 45 m. G.T.

(b) G.T. 6 h. 15 m. $112^{\circ} 22''$

8 8 $115^{\circ} 27''$

June 3.—Nucleus centrally situated in midst of head. Nucleus like a double-star 200° , $1''$. Δ m. 1.0, colour = 3, 3. An orange star, 7 mag.,

is N. p. comet. The double-star appearance persisted from 4 h. 45 m. to 6 h. 55 m. G.T.

June 4.—Nucleus larger than on last night. Yellow. It looks like a large double-star out-of-focus, angle 140° , dist. $4'' \pm$ almost resolved. (6 h. 30 m. G.T.)

June 8.—Nucleus is a stellar point of 7 mag. evenly surrounded by nebulosity.

June 10.—Resembles a ball of nebulosity very much brighter towards centre where a stellar point of 9th mag. is seen.

June 11.—(a) Stellar nucleus of $8\frac{3}{4}$ mag. in a round nebulosity.

(b) Very condensed, almost stellar, nucleus of 9 mag., which under a high power resembles a very dense unresolved globular cluster, surrounded by an even nebulosity. (5 h. 10 m. G.T.)

June 12.—Stellar nucleus in midst of a circular nebulosity $60''$ in diameter.

June 17.—Stellar nucleus 10 mag. Coma $1'$ in diameter. Strong moon.

June 24.—Naked eye = 5th mag. in all, no tail visible. In 9-in. stellar nucleus 9.5 mag.

June 26.—(b) Nucleus very condensed, but ill defined, $5\frac{1}{2}$ mag.

June 27.—Comet = 6 mag.

July 6.—Head gradually much brighter in middle, but no stellar nucleus seen.

NOTES BY FATHER E. GOETZ, BULAWAYO OBSERVATORY.*

April 15.—Halley's comet first visible to the naked eye.

April 17.—The tail appears double with a black streak centrally, starting from the nucleus. Telescope used : 5-inch refractor.

April 18.—The dark streak does not appear.

April 25.—Tail about 5° long.

April 30.—Tail about 7° long.

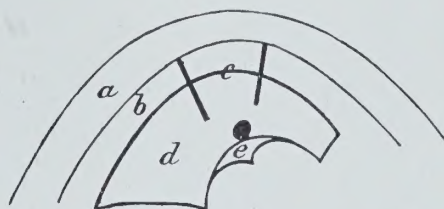
May 1, 2, and 3.—A slight curvature of the tail, the convexity being towards Venus.

May 12.—Comet seen nearly every morning up to date ; but nothing remarkable noticed. The tail has been steadily increasing. Nucleus near 58 Pisce and the tail ended near 35 Pegasus. The length of the tail is over 30° . The nucleus had an elongated form, the elongation being perpendicular to the sides. The nucleus is bright and yellowish. No streamers noticed

* Kindly communicated.

in the tail. Occasionally there seemed to be a black streak centrally, starting from the nucleus. No envelopes.

May 13.—A very fine object. It stretches from R.A. 0 h. 50 m. Dec. $+12^{\circ} 30'$ to the little group 37, 35, and 34 Pegasus. The nucleus is yellow; it is not spread out as it was on the 12th, but the coma is decidedly different; it contains a very bright envelope, in front of which at times there appears to be a fainter one. The bright envelope is not symmetrical; the southern or part away from the sun is much broader and longer than the northern or part nearer the sun. At times there appears right in front of the nucleus a much brighter patch. The general scheme is as follows:—



- (a) Hazy front of the coma.
- (b) Faint envelope seen at times.
- (c) Bright patch seen at times right in front of the nucleus.
- (d) Bright yellowish unsymmetrical envelope.
- (e) Dark spot at the back of the nucleus. Length of tail about 40° .

May 14.—Seen only for a few minutes. The tail ended in Equuleus, giving a total length of about 60° . The nucleus was small and bright, rather sharply defined, somewhat ruddy at times. The bright envelope seemed brighter, yellower, and larger than yesterday. The hazy part in front of the envelope has developed considerably. (Clouds from East.)

May 16.—Nucleus seen for a short time only; it was surrounded by more bright matter than two days ago. Glimpses of the tail seen between the clouds showed that it reaches as far as yesterday.

May 17.—Tail over 90° ; it penetrates into the Milky Way toward Scutum. The nucleus is too near the horizon to be observed in the telescope.

May 18.—The tail extends from the meridian to the horizon and is several degrees broad. The length must be over 140° . It is decidedly fainter than yesterday.

May 19.—As soon as the moon had set the tail of the comet appeared as a broad stream over 7° in breadth. It penetrated the Milky Way towards h Aquila or Scutum. It was not possible to say whether it emerged on the other side.

May 20.—At 4 h. A.M. the tail was seen in approximately the same place, but much fainter and narrower than yesterday. It was like the beam of a searchlight extending from the horizon to the meridian. It passed N. of η , ε and π Aquarius. It seemed to me that the night, after the moon had set, was darker than yesterday. Yesterday there was a faint whitish glow in the air which enabled me to see better and further than to-day. This may, however, be an effect of the imagination, as I rather expected to see some glow or other in the atmosphere.

The comet was seen for over an hour after sunset, length of tail about 15° . The nucleus appeared bright and surrounded by an envelope which ended in a point on both sides of it. The envelope was fairly symmetrical.

May 21.—The tail increases rapidly, it ended in the head of Hydra, 20° to 25° in length. Nucleus not well defined. The coma has a large bright unsymmetrical part. Two faint stars passed from the dark part behind the nucleus through the south part of the coma, close to the nucleus; they seemed at times to disappear, but if the eye is moved from the telescope they are spotted again at once. As the comet moved rapidly I watched these stars throughout their journey; when they emerged they did not appear appreciably brighter than when they were in the coma.

May 22.—Tail increased by several degrees. Envelope much fainter than yesterday.

May 24.—Nucleus not well defined, but envelope much brighter than two days ago, very unsymmetrical.

May 25.—Nucleus very bright, small, star-like, but ill-defined edges. No brilliant envelope in the coma.

May 27.—Nucleus small, bright, star-like, with ill-defined edges. Envelopes seem to have disappeared.

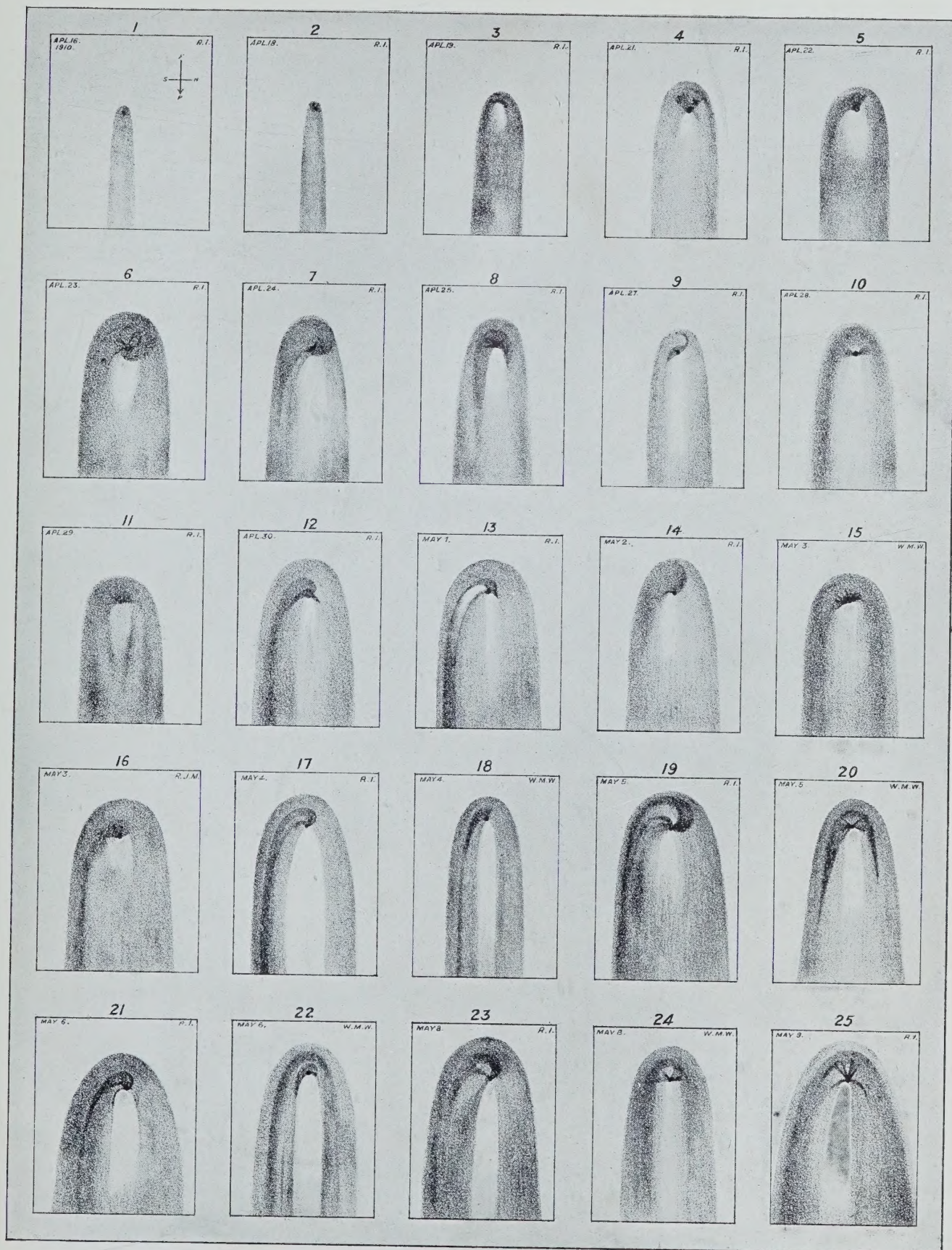


Plate X. Transvaal Observatory, Circular No. 4, July 11, 1910.

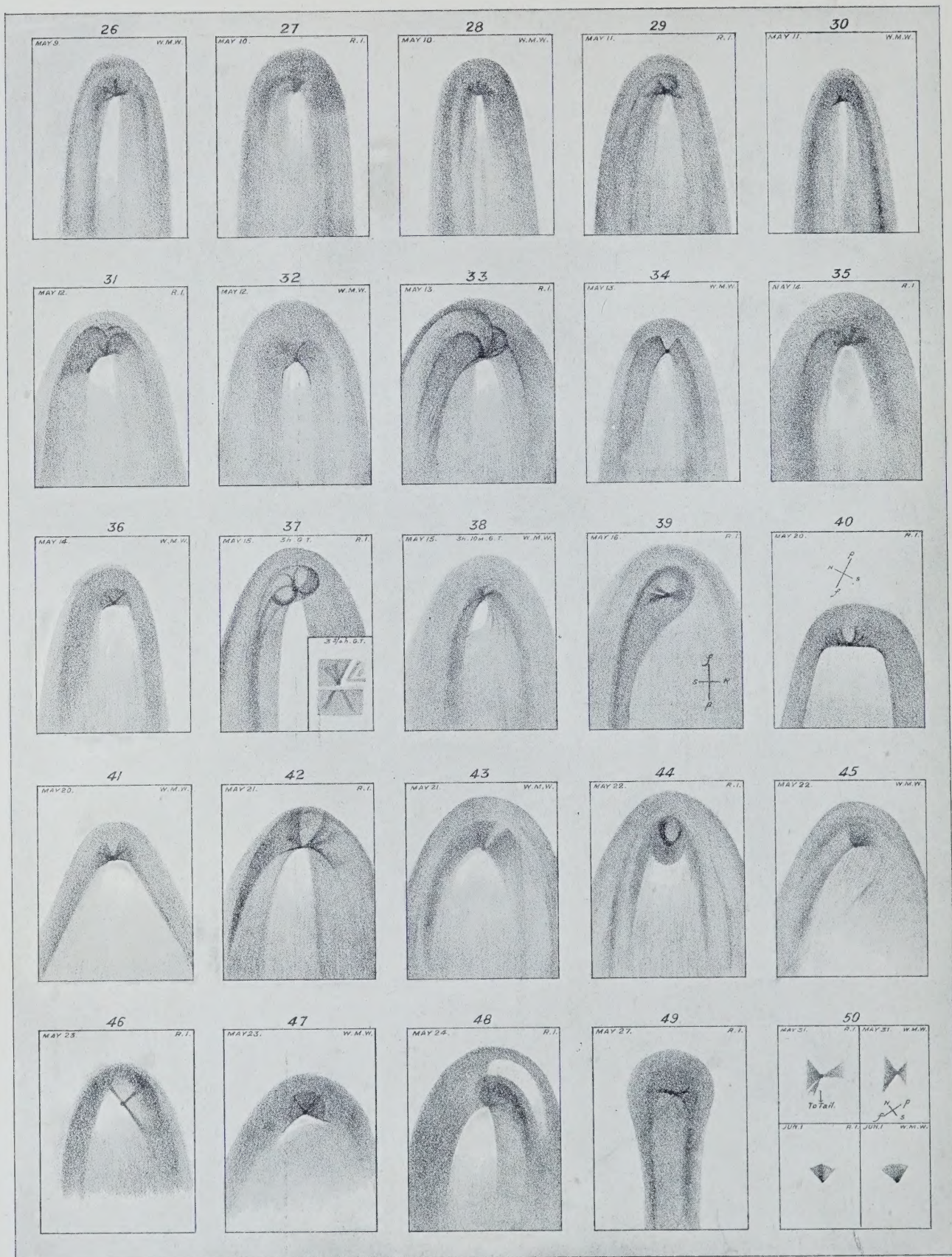


Plate XI. Transvaal Observatory, Circular No. 4, July 11, 1910.

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